THE DEVELOPMENT AND DIFFUSION OF THE AGRICULTURAL TRACTOR, 1880-1954

THESIS

Presented to the Graduate Council of
Southwest Texas State University
In Partial Fulfillment of
The Requirements

For the Degree

MASTER OF SCIENCE

By

James C. Murphy, BSME, MSEM

San Marcos, Texas

December 2002

DEDICATION

This thesis is dedicated first to my wife, Deanna, without whose indulgence during the long process leading to its completion, the effort would never have come to fruition.

Second, it is dedicated to my two children. I encouraged my daughter, Karen, to major in geography when she was an undergraduate, and with this project I have taken my own advice. I encouraged my son, Craig, to attend Southwest Texas State University, and again I have backed up my advice with deeds.

Finally, this work is dedicated to my three grandchildren; Murphy Brennan, Christina Murphy, and Thomas Murphy. It is hoped through this work that sometime in the future they may gain a better understanding of their engineer grandfather who returned to university in his 60s to get a degree in geography and write about tractors.

JCM

ACKNOWLEDGEMENTS

I wish to thank Dr. Brock J. Brown for his unflagging support throughout the research, writing, and preparation of this thesis. Thanks also to Dr. Fred M. Shelley and to Dr. Frederick A. Day for their counsel and review of the thesis. Their comments and suggestions made it a better thesis.

Dr. Richard L. Nostrand of the University of Oklahoma also provided counsel on portions of the research presented herein, and I thank him for his time and encouragement.

I further wish to thank the faculty and staff of the Department of Geography at Southwest Texas State University for their encouragement and facilitation in meeting the challenges and opportunities required for the Master of Science degree.

This manuscript was submitted on December 2, 2002.

CONTENTS

Chapter Page

Appendix

TABLES

Table		Page
Appendix B		

ILLUSTRATIONS

Figure Page

Chapter 5

Appendix A

Figure | Page

CHAPTER 1

INTRODUCTION

BACKGROUND

John Steinbeck's immortal novel *"The Grapes of Wrath"* opens during the Dust Bowl years of the 1930s (Steinbeck 1939). Tom Joad, the middle son of the Joad family and protagonist of the book, has just been released from prison in McAlester and has hitch-hiked westward to the farm where the family share-crops 40 acres. Upon his arrival he finds the place deserted and the property plowed. The house has been partially destroyed, having been knocked off its foundation. The plowing was done by tractor, creating long, straight furrows stretching over hill and dale, without regard for the house, the well, the dooryard or fence rows.

Reference is made to use of a *"Cat,"* so the tractor was undoubtedly an early Caterpillar diesel crawler. Caterpillar did, indeed, introduce a series of diesel models during the early to mid-30's ranging from a relatively modest 40 belt horsepower to a 118 belt horsepower model weighing in at a ground pounding 33,690 pounds (Wendel 1993). Tom is resentful of the situation, as are many other sharecroppers and small landholders forced off their land because of the one-two punches of the Great Depression and the Dust Bowl (Dust Bowl 2001). The problem is, upon whom or what does one focus pent-up resentment? The tractor is an inanimate object. In the book its driver is the son of a neighbor simply trying to feed his family. Tom learns that the property has been taken over by an eastern syndicate. While directives for plowing were issued by the local bank, orders were transmitted from an amorphous corporation *"back east."* Resignation was the ultimate attitude toward the overall situation and the technological phenomenon of the agricultural tractor as the displaced families were forced to move on, generally westward toward California.

Contrast this with the reaction of some early 19th century textile workers in England. Styling themselves as *"Luddites"* (named for a 1779 lad from Leicestershire of weak intellect who took out his frustrations at local tormentors by breaking some stocking manufacturing frames), these workers reacted to technology perceived to endanger their livelihood (not technology in general) by destroying the source of their fears. Organized bands (under the direction of a self-styled leader, *"General Ludd"*) originated in Nottingham in late 1811, and spread to Yorkshire, Lancashire, Derbyshire and Leicestershire. An economic depression in 1816 caused renewed rioting. Vigorous repressive measures, and then reviving prosperity ultimately brought the movement to an end (*The Encyclopedia Britannica*, 11th ed., s.v. "Luddites").

The contrasting reactions to technological development by these two groups encapsulates the shift in attitude from early 19th century to the second quarter of the 20th century. Where the Luddites reacted with fear, violence and destruction of the offending equipment, the *"Okies"* reacted with resentment and perhaps hostility but ultimately bowed to the inevitability of the technology represented by the agricultural tractor. Perhaps resentment and hostility were more widespread than just western Oklahoma, but in general the agricultural tractor was embraced as an emancipator, allowing the farm laborer to become an operator and mechanic rather than the centuries old role of laborer and sometimes beast of burden.

It is difficult today to exaggerate the extent of the agricultural tractor's impact on society. Halberstadt (2000, 110) expresses this sentiment by saying:

> *The tractor made every farmer an entrepreneur rather than a serf. It was the tool that provided the basis for the American economy, a system that encouraged independence. And it was the tractor that promoted free enterprise and rewarded individuals who were willing to risk becoming working capitalists.*

Today a cross-continent flight with a window seat will reveal millions of acres of plowed fields, with cultivation and harvest at some stage of the yearly cycle – all done with tractors. In the Rural Heartland one will see millions of acres of *"amber waves of grain"* – all planted, cultivated, and harvested with tractors as the motive power. Every radish, every rutabaga, and every other row crop in California's Central Valley was brought to harvest via tractor power. The beefsteaks, chicken fryers, lamb chops, and pork loins in the nation's grocery stores and meat markets were nurtured and prepared for market with the aid of a tractor. It is safe to say that the agricultural tractor provides the heartbeat for the nation's agribusiness in providing food for the tables of the U.S. as well as major parts of the rest of the world.

DEVELOPMENT AND DIFFUSION PROCESSES

Development must precede diffusion, since an innovation must be at such a state as to entice the earliest adopters to risk their personal currency (time, money, social standing) and make a positive adoption decision. Once the diffusion process is under way, further development will follow as the realized and potential impact of the innovation are realized. This process is especially true of a technological innovation.

The term *"diffusion of innovation"* refers to the process whereby something is spread and adopted over space and time by a community of individuals. An innovation may be a new hairstyle, a new treatment for an infectious disease, a new belief system, a new hygienic practice, or a technological development as the agricultural tractor. While the diffusion process varies with each innovation, certain characteristics of the innovation, the would-be target adopters, the temporal and spatial considerations, and exogenous forces at work all play a role in the ultimate success or failure of the diffusion process. This broad set of characteristics can be examined to distinguish historical patterns, identify the progress and status of current diffusion processes, and possibly anticipate future diffusion trends. Through such studies, greater penetration of the target market, and a reduction of time of the process may be possible.

In this thesis, I trace prerequisites for technological innovation in the context of historical developments leading to the technology availability for tractor development in the late 19th century. An initial purpose here is to demonstrate that a technological innovation cannot become reality until certain social, geographical, and technological prerequisites are in place. Once these prerequisites are in place, an innovation may be developed to the point where initial acceptance by a segment of the target market is possible. Second, once the process of diffusion is underway, feedback from current and would be adopters may cause enhancements to the innovation and the hastening of the adoption process by would be adopters. This feedback process is especially amenable to diffusion of technological innovation.

CONTEXT OF THE THESIS

According to Professor Angus Maddison (2000), per capita income was $675 per annum in 1820 expressed in 1990 dollars (he considers 1820 to be the time the Industrial Revolution was well and truly underway). In the following 170 years per capita income exploded to more than $5,000 world-wide and nearly $20,000 in the advanced economies of the West. So, assuming that yearly per capita income across the globe in 40,000 B. C. (the time of Homo Sapiens' emergence in its current incarnation) was $0.00, then during the first 41,820 years of Homo Sapiens, the population rose 400 percent while per capita income rose by $0.016 per year. Then, in the ensuing 170 years, population rose by 495 percent and per capita income rose by $25 per year.

Obviously dramatic events took place in the noted 170 years from 1820 to 1990. This was, of course, essentially the period of the Industrial Revolution from 1750 to 1900 plus 90 years of post-industrial consolidation and additional advancement. At the start of the Industrial Revolution, the majority of world population consisted of subsistence farmers who, perhaps, sold a bit of surplus production for staples such as salt, sugar and services such as blacksmithing. Oxen, horses, and mules were beasts of burden. Plows were made of wood. Sowing was done by hand, cultivating by hoe, hay and grain cutting by sickle and threshing was done by flail. These were the tools of agriculture – little changed – since the Middle Ages (USDA 2001).

Schlebecker (1977b, 646) quotes Carl O. Sauer to the effect that:

> *Agriculture did not originate from a growing or chronic shortage of food. People living in the shadow of famine do not have the means or time to undertake the slow leisurely experimental steps out of which a better and different food supply is to develop in a somewhat distant future. . . . The needy and miserable societies are not inventive, for they lack the leisure for reflection, experimentation, and discussion.*

To accomplish the above-described socioeconomic gains, the production of food had to outpace the rest of the economy. This was required in order for enough capital to be freed for the technological advancement – both agriculturally and industrially. It was required to provide the basics for the exploding population while increasing the per capita income, roughly translating into standard of living, by a factor of 7.4 ($5,000/675 = 7.4).

Thus, an agricultural revolution occurred simultaneously with and as part of the Industrial Revolution. This agricultural revolution took the form of applying the same advances in technology developed in the Industrial Revolution and applying them to the agricultural sector. The studies included in this thesis commence in the final years of the Industrial Revolution when the demand for power in the field could no longer be met with draft animals. First wheel-mounted steam engines were drawn into the fields with draft animals. By 1880 the steam engine was being used to supply its own motive power, and became known as the steam traction engine. Steam power soon was being replaced with internal combustion engines, and the era of the gasoline traction engine (tractor) commenced in the first decade of the 20th century.

THEORIES EXAMINED

As implied in the title of the thesis, two aspects of the total diffusion process are examined. First, I examine the technological development of the tractor and the prerequisites necessary for development to take place. Second, the diffusion process itself is examined with conclusions reached as to the overall process and a new perspective on how the process may be viewed.

It is asserted in the thesis that technological development requires that a number of prerequisites be in place before development can actually occur (Murphy 1998). Implicit in this prerequisite concept is that some number of these prerequisites must be present *in sufficient strength* for a critical mass of consumer demand or (alternatively) developer expectation, to trigger development. At that time, technological development may go forward as a result of market demand or developer initiative (Murphy 1998).

The same prerequisites demanded for development of the agricultural tractor existed for other innovations of the Industrial Revolution as well. Nowhere was this truer than in the development of agricultural implements where such advancements as the iron plow (1819), a practical threshing machine (1830), and the sulky plow (1859) were developed in advance of a steam traction engine (Hackett and Rukes 2001).

Prerequisites are defined in this thesis as falling into cultural, geographic, and technological categories. Social and geographic prerequisites relate to the cultural and societal consideration required for development to be initiated. Technical prerequisites relate to the state of technology required to be in place for development to be initiated. These prerequisites are examined individually as to their particular relevance in the creation of a critical mass leading to the initiation of development of the agricultural tractor. This involves examining the physical components of the tractor (such as the source of motive power, the chassis, drive train, spring mounting, wheels, and instrumentation) and identifying the required prerequisites for that component to be built. All prerequisites need not be in place at the same level of sophistication. Some evolve during the course of development itself. A steam engine mounted on a chassis but drawn into the field by a horse need not have a drive train. Once the decision was made to make the device self-propelled, a gearing mechanism and differential had to be developed. Once developed they became available for subsequent adoption on other innovations including automobiles as well as tractors.

Once the analysis has identified a critical mass of prerequisites in place, the emphasis of the thesis shifts to the tractor industry itself as the vehicle for tracing tractor development and diffusion. Pioneers and pioneering companies are reviewed, and the maturation process from small companies, through acquisition and mergers into larger companies, departure from the market by companies, and the final stage of conglomerate ownership are examined. These steps occurred as a result of the evolving technology, and the changing exogenous forces as familial, societal, economic, and political/ governmental conditions of the era.

Rogers (1995, 5) defines diffusion as: *"the process by which an innovation is communicated through certain channels over time among the members of a social system."* In his definition of the diffusion process, there are four elements: the innovation itself, communication channels, the time period, and the social system. This diffusion process has been confined, for purposes of this study, to the start of diffusion of the gasoline traction engine until tractors exceeded draft animals on the farms of America. Finally, of course, are the members of a social system – here America's farmers in particular and those in agribusiness in general. Conspicuously missing from Rogers' definition is the areal aspect of diffusion. Of course, diffusion *does* take place over space as well as time, and that aspect of diffusion is included in this analysis.

Finally, the social system is addressed in the context of development and presentation of an association matrix. The association matrix is a construct in which rows consist of the categories of adopters (innovators, early adopters, early majority, late majority, and laggards) and columns consist of the five characteristics of the innovation (relative advantage, compatibility, complexity, trialibility, and observability) (Rogers 1995). The matrix is populated with an association index for each of the 25 combinations of adopter category and innovation characteristic. The association index represents a subjective determination of the importance of each of the innovation characteristics on each of the adopter categories at the time at which the adoption decision was being made. The social, temporal, and areal aspects of the time play a role in each of the index determinations, as do the exogenous forces (economic boom, war, drought, depression) at work at that time. Having assigned association index values, one can sum the row values and column values as another analysis tool. As indicated in this thesis, the resulting values support the hypothesis that diffusion of innovation is amenable to examination via this structured analytical approach.

This thesis consists of the current introductory chapter and five additional chapters:

Chapter 2 provides a literature review and background for the two major issues addressed during the course of the thesis, namely prerequisites and development of the agricultural tractor industry and tractors themselves, and diffusion process. The presentation is thematic with subsections arranged chronologically where appropriate.

Chapter 3 is a methodology chapter. It provides a compendium of the topics and presentation of the rest of the thesis as well as the procedural approach in information acquisition, analysis, and presentation.

Chapter 4 provides the analysis and assessment of the prerequisites and development aspects of the tractor industry in the U.S. Prerequisites are defined and discussed as to the time and circumstances of availability vis-à-vis the development of the tractor. The tractor industry itself is described in spatial and temporal terms with emphasis on technological developments aiding in, and derived from, its diffusion.

Chapter 5 presents the diffusion analysis and proposes a new *"association matrix"* which allows a structured approach to the subjective problems of determining the impact of the characteristics of a technological innovation upon each of the adopter categories described in the literature.

Chapter 6 presents conclusions concerning the development and diffusion of the tractor, and discusses possibilities for further research stemming from the work and approaches to analysis presented previously.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Diffusion of the agricultural tractor in America, first in the Rural Heartland and then in other identifiable regions (as the Plantation South) during the early 20th century played a major role in reshaping farm life in America. Its impact ultimately improved other aspects of American culture. The daily diet of the American people was expanded. Migratory trends of farmers and farm hands from farming to urban communities were exacerbated. Reapportionment of land use as draft animals and their feed requirements diminished was a direct result of tractor diffusion. Surprisingly, the spatial and temporal process of the diffusion of the tractor, however, has not been thoroughly studied.

This thesis focuses on two aspects of the diffusion of the tractor in the United States. First, the existence of prerequisites necessary for development of the tractor as an example of a technological innovation, and tractor development itself are investigated by examining the individuals and companies with significant impact on the maturation of the tractor industry. Secondly, the specific process of diffusion of the tractor is presented with emphasis on the exogenous forces acting as incentives and barriers that were instrumental in the diffusion process. Some aspects of the consequences of tractor diffusion are examined with emphasis on their role in fostering more development and expanding diffusion.

A considerable body of literature is available as a basis for this thesis – little of it directly available from traditional geographic sources. In fact, despite the obvious spatial element in any diffusion analysis, Rogers (1995) notes that only four percent of the available literature on diffusion derives from geographical sources. He further notes that the golden age of diffusion research occurred in the 1950s and 1960s when, particularly, rural sociologists where studying techniques for the diffusion of then-new technological developments to farmers (for example the diffusion of hybrid corn in Iowa (Rogers 1995)). One may wish to note that Rogers himself was a rural sociologist. Also curious is that despite rural sociologists' interest in diffusion in general during the 1950s and 1960s, few articles in the published literature found to date relate specifically to the agricultural tractor. This research begins documentation of this phenomenon.

PREREQUISITES AND DEVELOPMENT

Innovation over time does not occur independently but is the culmination of the congruence of earlier development efforts. It is asserted here that technological development is constrained by a requirement that some number of prerequisites be in place (both culturally and geographically, and technically (Table 1)) in order for new development of an innovation to occur. Taking this assertion to the extreme, we would need to initiate our examination of the tractor with development of the first tool – the

TABLE 1
PREREQUISITES FOR TECHNOLOGICAL DEVELOPMENT

Cultural & Geographical Considerations
Geography
Population
Laws, Legal Manipulation & Precedent
Spatially Derived Need/Opportunity
Socio-Political – Including War
Business Policy Financial Wherewithal
Technological Considerations
Cross-Industry Synergy
Manpower Pool
Engineering, Physics & Heuristic Development
Organizational Constructs
Manufacturing Processes
Applied Mathematics

(Murphy 1998)

lever. Ignoring such prehistoric advancement, however, a good place to start is the perspective provided by Landels (1978) on engineering in the ancient world. Landels provides background information on topics as power and energy sources (including manpower, animal power, and steam power), and the progress of theoretical knowledge – all necessary as a prerequisite to the Baroque period, the Industrial Revolution, and the ultimate development and diffusion of the tractor in the United States. In the following paragraphs I trace each of these prerequisites as they impact the initiation of tractor development.

Prerequisites and the Baroque Period

The Baroque (or Baroco) period is generally best known for and is identified as a florid, ornate style characterizing fine arts, particularly architecture, furniture and household decoration in Europe from middle 16th to middle 18th centuries.

Beyond the florid architectural styles, however, were significant technological and legal developments which provided some of the final prerequisites for the inception of the Industrial Revolution. A number of advances in humankind's understanding of nature and the use of mathematics and technology to quantify natural law were developed. From the 17th to 18th centuries a transformation occurred in which the concept of natural law resulting from divine decree evolved into a more secularized view in which natural law was mathematically quantified with no individual exceptions as was common for Royal Decree (Stearns 1993). Table 2 shows some of the individuals and

TABLE 2
SOME KEY INNOVATIONS OF THE BAROQUE PERIOD

Developer	Innovation
Galileo	Computing machines and physics
Kepler	Physics and astronomy
Leibnitz, Huygens & Newton	Theoretical and experimental development in mathematical methods for quantifying natural law
Descartes, Spinoza & Leibnitz	Philosophical view of a world governed by natural law

(Klemm 1964, 169)

their work exemplifying this trend. The period was critical in areas of mathematics which would later form the backbone of engineering mathematics. Isaac Newton pursued analytic geometry, infinite series, and calculus in his investigations. His method of fluxions and fluents became the differential and integral calculus – with which he demonstrated that derivatives and integrals were inversely related. The developments of

Newton have, more than any other techniques, made possible the use of the mathematical model in the expression of physical and mechanical phenomena (Klemm 1964).

From a purely technical standpoint, significant development took place in scientific instruments and devices, including the microscope, telescope, barometer, a form of calculating machine, the air pump, the pendulum clock and the thermometer. Such developments were absolutely essential to the launching of the Industrial Revolution since it is impossible to conceive, for instance, of the generation of steam and its conversion to work without the availability of a thermometer. Similarly, while the problem of calculation of longitude had been recognized for hundreds of years (Sobel 1996), development of the naval chronometer as a successor of the sundial or hourglass without first going through the intervening development of the pendulum clock would not have been possible.

Finally, the concept of intellectual property of the individual was addressed in a series of issues. As early as the Middle Ages inventors were granted *"privileges"* as protection from imitation. During the 16th century in Central Europe (the Netherlands and Saxony) formulae were developed for defining an intellectual property based on its utility and novelty. In England, however, there persisted through the late 16th century the practice of awarding *"Crown Privilege"* as a form of patronage (Stearns 1993). This practice began to be challenged during the early part of the 17th century, and while it was the end of the 18th century before a patent law was in place, the practice of bestowing Crown Privilege based on the intellectual property rights of the inventor became the norm. This allowed technological development to move forward much more rapidly in England than on the continent. The fledgling United States recognized the importance of patent law and the protection of intellectual property as early as 1790 - a mere year after the ratification of the Constitution.

Table 3 shows a representative list of Baroque period inventions and inventors.

TABLE 3
REPRESENTATIVE BAROQUE PERIOD INVENTIONS/INNOVATIONS

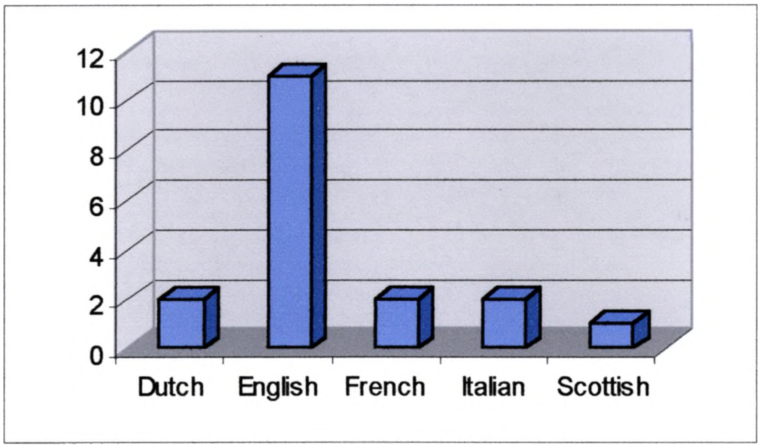
Invention	Date	Inventor	Nationality	Category
Knitting machine	1589	William Lee	English	C&C
Compound microscope	1590	Zacharias Janssen	Dutch	SI&D
Thermometer	1593	Galileo	Italian	SI&D
Blood transfusion	1625	Jean-Baptiste Denys	French	M&B
Micrometer	1636	W Gascoigne	English	IndM
Adding machine	1642	Blaise Pascal	French	CM&C
Barometer	1643	Evangelista Torricelli	Italian	SI&D
Pendulum clock	1656	Christiaan Huygens	Dutch	SI&D
Reflecting telescope	1668	Isaac Newton	English	SI&D
Steam pump	1698	Thomas Savery	English	E&T
Seed drill	1701	Jethro Tull	English	F&A
Steam engine, reciprocating	1705	Thomas Newcomen	English	E&T
Diving bell	1717	Edmund Halley	English	E&T
Stereotyping	1725	William Ged	Scottish	Comm
Flying shuttle	1733	John Kay	English	C&C
Achromatic lens	1733	Chester M Hall	English	SI&D
Crucible steel process	1740	Benjamin Huntsman	English	IndM
Marine chronometer	1749	John Harrison	English	SI&D

Where:

Abbreviation	Category
CM&C	Calculating Machines and Computers
C&C	Cloth & Clothing
Comm	Communication
Const	Construction
E&E	Electricity and Electronics
F&A	Food and Agriculture
IndM	Industrial Materials
M&B	Medicine and Biotechnology
SI&D	Scientific Instruments and Devices
E&T	Energy and Transportation
War	Warfare

(*Compton's interactive encyclopedia.* 1997 s.v. "Baroque Period").

It is notable that while the Baroque period is identified by activities of an artistic and whimsical nature, these activities chiefly originated in France and Italy. The list of inventions and inventors became dominated by English and Scottish activities (Figure 1).



(Compton's interactive encyclopedia 1997, s.v. "Baroque Period")

Figure 1. Distribution of Baroque Period innovations.

And so, the Baroque period provided both technical and geopolitical (as related to the focusing of technological development in the British Isles) prerequisites for the Industrial Revolution in applied mathematics, physics, manufacturing and in social acceptance of natural law, plus recognition of intellectual property in the form of legal precedent via patent law. While the continent of Europe perfected the Baroque art forms, Great Britain was (without planning thus) setting the stage for the technological phenomena of the Industrial Revolution. From the standpoint of technological development, then, the Baroque period acted as a prerequisite to the Industrial Revolution.

Prerequisites and the Industrial Revolution

An immediate and necessary precursor to the agricultural tractor era was the Industrial Revolution which set the stage for, and provided the final prerequisites for, tractor development. Farmers had worked the land in a manner essentially using the tools and techniques of their forefathers and grandfathers before them. Generations might pass between notable innovations in farming tools and techniques.

Then the Industrial Revolution commenced (nominally) in 1760. Not surprisingly, an agricultural equipment revolution occurred simultaneously or as an integral part of the Industrial Revolution. Production of agricultural implements and the means of production thereof followed the same path as that of industrial tools and equipment. During the Industrial Revolution two key manufacturing processes began to emerge. First was the move to interchangeable parts. Eli Whitney was instrumental in moving the process forward. After his success with the invention of the cotton gin in 1793 failed to make him any significant amount of money (the gin being too easy to copy), Whitney turned to the manufacture of arms. After 1800 he gained notoriety while striving to fulfill government contracts calling for weapons with interchangeable parts. Though his efforts were not totally successful (parts still needed to be filed for fitting into a new weapon) the process was moved along and would ultimately be successful. Second was the practice of machines manufacturing machines. This process was predicated on interchangeably of parts (Cochran 1983). Once the cycle of improved manufacturing processes was set in motion, all facets of the process, including materials, metallurgy, instrumentation, and machining became involved in an ever-widening demand for improved components and processes. Thus the manufacture of household goods (including stoves), building of steel hulled, steam driven ships, arms manufacture, construction trade tools and equipment all contributed to a cross-industry synergy which encompassed the manufacture of agricultural equipment as well (Murphy 1998).

As the Industrial Revolution acquired momentum during the early years of the nineteenth century, there was an inexorable movement toward mechanization on America's farms. In 1819 Jethro Pugh patented an iron plow with interchangeable parts. Cyrus H. McCormick patented his threshing machine in 1834. In 1836 John Deere made his first plow faced with steel saw blade. During the 1840s the move to factory-made farm machinery (including a practical grain drill, patenting of a practical mowing machine, and the first portable steam engines for farm use (drawn by draft animals)) required that the farmer make capital investments on a scale never before required. This in turn increased the farmer's need for cash and encouraged the migration from subsistence to commercial farming. The remainder of the 19^{th} century saw additional advances. A two horse straddle-row cultivator was patented (1856); gang and sulky plows came into use (1865-75); barbed wire was patented (1874); and a horse-drawn combine was used in the Pacific coast wheat areas (1884-1890) to name but a few of the innovations (USDA 2001). The inclusion of more and enhanced equipment in the agricultural process produced astounding results both before and after the introduction of the agricultural tractor. Two examples demonstrate this increase in production. Extracting from the United States Department of Agriculture (USDA 2001), Figures 2 and 3 provide examples of the return on investment for equipment as reflected in the production of corn and wheat (mainstay crops of the Rural Heartland).

Note that the production costs (expressed in labor hours to produce a bushel) decreased from 90 to 40 hours for corn during the 1830 to 1890 time frame while an even more dramatic decrease from 300 to 50 hours was achieved between 1850 to 1890 for

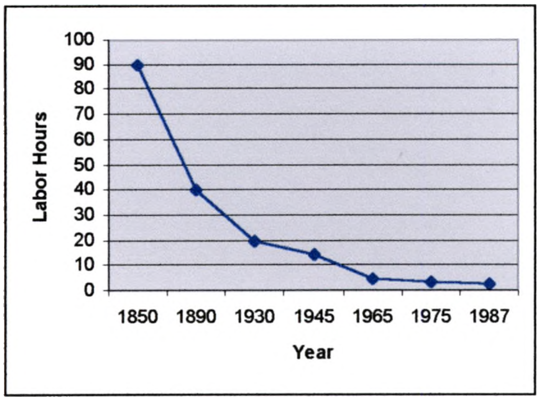


Figure 2. Labor hours to produce 100 bushels of corn (2.5 acres).

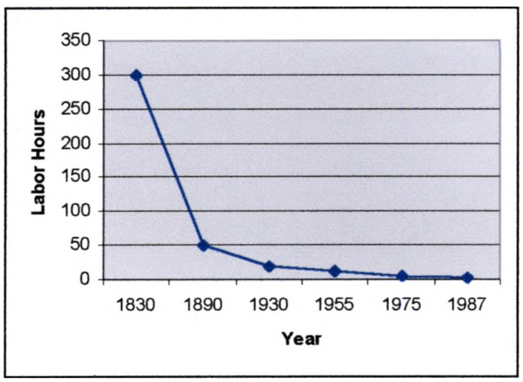


Figure 3. Labor hours to produce 100 bushels of wheat (5 acres).

wheat. The very success of these new tools generated a demand for additional power in the field as witnessed by the appearance of wheel-mounted steam engines, and thus an incipient demand for steam and ultimately gasoline traction engines.

Individual authors chronicle the slow, but inexorable progress toward these technological prerequisites. Mott (1997) provides detail on the development and diffusion of the pintel-gudgeon rudder during its 500-year displacement of the half rudder – demonstrating early understanding and advancements in mechanics, structural considerations in ship design, and hydraulics. Sobel (1996) presents a fascinating description of the difficulties encountered and overcome by John Harrison (sometimes nicknamed Longitude Harrison) in the development of the naval chronometer during the 1730-1770 period. Harrison's solution required a very precise clock set to noon on Greenwich Mean Time prior to the start of a voyage. As the ship proceeded east or west, the angle of the sun at noon local time allowed determination of the degrees traveled since leaving England. In the process of his work, Harrison advanced techniques in manufacturing highly precise cogwheels, and made strides in metallurgy and understanding of metallic coefficients of expansion in order to produce a clock spring impervious to changing temperatures, humidity, and barometric pressures.

Such advances in metallurgy, machining, understanding of hydraulics and engineering modeling of hydrological forces, and the ability to create extremely accurate instruments such as the naval chronometer (and to test and confirm their accuracy) were essential to subsequent engineering advancements. They provided the technological prerequisites necessary for development of first the steam engine and subsequently the internal combustion engine.

That technological progress would continue (and certainly in the directions actually achieved) was not a sure thing. Malthus (1798) questioned humankind's ability to cope with an exponentially expanding population vs. perceived finite natural resources (whose production was progressing arithmetically) during the latter years of the 18^{th} century. At this early time in the Industrial Revolution, it was not immediately obvious that enhanced technology could postpone a crisis of worldwide starvation for any great period.

With the progression of the Industrial Revolution, the list of prerequisites in place for the technology required for tractor development lengthened. Previous work by the author (Murphy 1998) provides the basis for much of this discussion. First, a reasonable definition for the word *"technology"* must be presented. Funk & Wagnals dictionary indicates that four constituent parts must be present. These include:

> *Theoretical knowledge of industry and the industrial arts,*
>
> *the application of science and of technical advances in industry, manufacturing, commerce and the arts,*
>
> *the technical language of an art, science, etc., and*
>
> *the means by which material things are produced, as in a particular civilization.* (*Funk & Wagnalls standard college dictionary.* 1977, s.v. "technology").

Using this as a base then, technology would include the pure sciences of mathematics and physics, natural sciences as biology, botany and geology, chemistry; engineering (and such associated fields as metallurgy, materials development and instrumentation), manufacturing processes and all the areas currently described as medical science.

Many historians (Schlebecker 1977b) indicate that four elements must be present for technological innovation to proceed:

> *cumulated knowledge*
>
> *evident need*
>
> *economic possibility, and*
>
> *cultural and social acceptability.*

While not disputing this enumeration, it appears to this author to be overly simplistic. It has previously been asserted here that the categories of cultural and geographical considerations, and technological considerations presented in Table 1, provide a broader platform for discussing technological development. By way of example, the concept of cross-industry synergy is illustrated by the triangle of locomotive manufacture, a broadly competent machine tool industry, and the textile industry. As the Industrial Revolution was driven by the textile industry, mills brought in mechanics to build their mostly wooden machinery by hand on site. There were a few large mills selling machinery and a very few specialized shops selling all types of spinning and weaving equipment from standard patterns. An immediate effect of the spread of the railroads was a demand for rolling stock. This demand created a market for specialized machine tool factories capable of manufacturing engine parts as boilers, frames, axles, and wheels, plus a demand for the tools of production itself: lathes, drills, milling machines, filing jigs, gear cutters, and the like. To keep pace with this demand, the U.S. competed with Britain in development and manufacture of machine tools. By 1828 some experts found American machine tools superior to those manufactured in Britain (Cochran 1983). The ability to manufacture precision parts on an assembly line basis then fed back to the textile industry where weaving and spinning equipment came to be manufactured by third party manufacturers (Himdle and Lubar 1988). This pattern extended to manufacture of farm implements (and ultimately the tractor), household goods including stoves, the building of steel hulled ships equipped with steam propulsion, arms manufacture, construction trade tools and equipment. Such cross-industry synergy represents one of the significant prerequisites for technological development, not immediately obvious from the list presented by Schlebecker.

Evolution of the Tractor Industry

Once development and actual manufacture of the agricultural tractor commenced, the discussion shifts to individuals and companies pioneering in the new industry. Through this approach the thesis traces the maturation of the tractor industry, the trends in model offerings, and the enhancements provided.

Development Trends

Carroll (1998) provides a cross-manufacturer examination of the tractor industry and products. An initial section describes early patents pending (1900-1920). During the early years a large number of patents were introduced as the new technology was investigated and exploited. Tracing patents filed is analogous to tracing the technological progress during the early stages. In 1892 John Froelich constructed a tractor consisting of a converted steam traction engine chassis, a transmission of his own design, and a Van Duzen one cylinder gasoline engine. This tractor is considered to be the first workable internal combustion powered tractor, gaining much notoriety when it was used over a seven-week period for threshing on a South Dakota wheat farm. Froelich then formed the Waterloo Gasoline Traction Engine Company with a group of investors. Despite this early success, no further tractors were manufactured by the company until 1912. As mentioned previously, Waterloo Gasoline Traction Engine Company was ultimately acquired by John Deere Company in 1918 (Halberstadt 2000; Deere 1994). During this period of experimentation, many ideas originating from many individuals and companies were conceived and immediately discarded, others were patented and incorporated long term, or ultimately dropped from standard tractor design. Three wheel tractors were tried. Chain driven tractors were tried. The Advance-Rumely Company of La Porte, IN perfected a carburetor capable of processing kerosene or paraffin for their OilPull line of tractors.

The period saw the start of the move to smaller tractors as the needs of farmers in Great Britain during World War I influenced design. The Fordson F is, perhaps, the embodiment of this trend. Ford also produced tractors in Scotland (marketed as the Glasgow) for a period between 1919 to 1924. Here he experimented with a three wheeled tractor with a single drive wheel in the rear to obviate the need for a differential. While most such innovations were ultimately discarded, examination of this period provides a picture of the shaping of the tractor by seeing what *did not* work. Carroll (1998) also addresses mass production from 1920 to 1940 and during World War II. These periods include the shakeout of smaller, undercapitalized firms incapable of making the investments required for mass production techniques, and introduction of new technology (including pneumatic tires to replace steel wheels with lugs, and the power take off (PTO). During World War II tractor production became a part of the overall resource allocation scheme to meet wartime needs. Early in the war, the U.S. supplied Great Britain with significant numbers of tractors under the Lend-Lease program (Williams 1992a). Prominent in this effort were Allis-Chalmers, J. I. Case, John Deere, Caterpillar, Minneapolis-Moline, Massey-Harris, Oliver, International Harvester and Ford (all of whose genealogy are discussed in this thesis as part of the overall picture of the tractor industry development and maturation process).

Pioneers, Pioneering Companies, and Maturation of the Tractor Industry

The tractor industry as a whole has undergone an evolution similar to that of other industries such as railroad rolling stock, automobiles, airplanes, and more recently televisions and personal computers. In the infancy of the industry, many firms entered the market on a small scale and frequently were undercapitalized. Most of these companies either went out of business, were acquired, or merged with other companies. Over the years, some 400 companies ranging from Bates Steel Mule to Little Chief to Steel Hoof to Yankee Boy (Sanders 1996) have had products on the market. General Motors entered the competition for a time with its Samson Iron Horse line (Carroll 1998). Only the strongest survived, embodying dedication, good engineering, good management, good financing, good marketing, and good dealer support in some combination.

Thirteen companies are examined in this thesis as representative of the industry as a whole. The story of key individuals, the genealogy of firms, corporate production data, target markets, and key models are all combined to present a picture of the development aspects segueing into manufacture and thus leading to diffusion. The companies chosen include AGCO, Allis-Chalmers, J. I. Case, Caterpillar, Cockshutt, John Deere, Deutz AG, Ford, International Harvester, Massey-Harris-Ferguson, Minneapolis-Moline, Oliver, and White Farm Equipment. An additional four firms, including Advance-Rumely, David Brown, Emerson-Brantingham, and Hart & Parr, are included where they played a significant role as acquired companies by the major or surviving firms listed above.

The implications of Ford's entry into the tractor industry are numerous. First, Ford was the only major automobile manufacturer to enter and stay in the tractor business. Second, Ford used the synergism provided by the automotive works to mass-produce an inexpensive tractor. Finally, Ford tractors introduced numerous innovations including the Ferguson system three-point hitch (Pripps and Moreland 1992). Henry Ford (1923), and his long-time production chief, Charles E. Sorensen (1956), provide insight and the ultimate insiders' perspective into the operation of Ford Motor Company during its formative years. Ford provides an introspective view of himself, his company, and his philosophy of life as embodied by his company. Perhaps there is no better commentary on Ford's philosophy regarding the introduction of Ford tractors than this quote:

> *The automobile is designed to carry; the tractor is designed to pull . . . The public was more interested in being carried than in being pulled; the horseless carriage made a greater appeal to the imagination. And so it was that I practically dropped work on the tractor until the automobile was in production. With the automobile on the farms, the tractor became a necessity.*
> (Ford 1923, 200)

Sorensen (1956) tracked his own employment at Ford starting in 1905 in the pattern department at $3.00 per day, through to his retirement in 1944. Together these two men were primarily responsible for the manufacturing process of the Model T, the large-scale application of the moving assembly line for mass production. Sorensen also influenced development of the River Rouge plant (raw materials in at one end – cars and tractors out the other), handling of tractor production, the $5.00 per day wage, and Ford's handling of the New Deal. Henry Ford and the Ford Motor Company played as significant a role in the development of the tractor as they did in development of the automobile. The Model T Ford was introduced in 1908 and production continued until 1926 during which time some 15 *million* Model Ts were produced. Such production was only possible through

Ford's development of the moving assembly line. However, hundreds of Ford innovations from new alloys for transmissions to the introduction of a multi-cylinder cast engine block with separate cylinder head were all available when the Fordson F tractor was introduced to American consumers in 1917. Ford and Sorensen also describe the early tractor experimentation at Ford, and the initial decision to introduce Fordson tractors under the Henry Ford and Son Company name. Ford had established Henry Ford and Son as a separate company from Ford Motor Company to do tractor research and development out of his own pocket. Later, when Ford was engaged in a fight for total ownership of Ford Motor Company with his minority shareholders, he resigned his presidency of the company. He then used the viability of Henry Ford and Son, with its tractor production and the threat of the manufacture of a rival car to the Model T, to force out his limited partnership stockholders. Ford Motor Company remained in total possession of the Ford family until going public in 1946.

Considerable coverage is given to the manufacture of Fordsons for the British Ministry of Munitions during the World War I years (leading to Ford's introduction of the tractor into the U.S. retail market), the movement of tractor operations to Ireland, and the subsequent re-entry into the U.S. market. An early marketing brochure by Ford (Ford Motor Company 1919) describes in glowing terms its initial entry into tractor manufacture with emphasis on the Fordson's role as every man's tractor and a replacement for draft animals on small farms. By 1925 Ford had produced 550,000 tractors and had forced the tractor industry into mass production of an inexpensive tractor for the small farmer in just the same way that the Model T forced other auto manufacturers to provide automobiles affordable by the masses. The massive economies of scale involving both the automotive and tractor works allowed the transfer of men and equipment between the two and allowed the raw material purchases to be folded together as well. Many of the undercapitalized competitors were forced out of business by this synergism (Sorensen 1956). For instance, in 1921 there were 166 companies in North America with a production capacity of perhaps 200,000 tractors per year. In what came to be known as the tractor price wars, Ford slashed prices from $785 to an ultimate low of $395 (in then-current dollars). Ford managed to sell 35,000 units in 1921, 67,000 units in 1922, and more than 100,000 units in 1923. By the time the price was war over, there were only about ten manufacturers of any consequence operating in the U.S. (Pripps and Morland1997).

John Deere and Company has been a major manufacturer of agricultural and now garden tractors, and is today one of the last-remaining manufacturers continuing independent operations with the same corporate identity throughout its history. Deere is also representative of the early entrants in the tractor manufacturing business whose roots lay in the agricultural implements industry. The antecedent company of the present John Deere, Grand Detour Plow Co. of Grand Detour, IL, was formed by a blacksmith named John Deere in 1843. Deere produced some 100 steel-faced plows in the company's first year of operation (Deere 1988, 1994). By 1852, now named Deere, Tate & Gould, the firm manufactured 4,000 such plows. For the next 66 years the company continued to be a significant player in the agricultural implements industry. The company entered the tractor business in 1918 through acquisition of the Waterloo Gasoline Traction Engine Co., manufacturer of the Waterloo Boy tractor line. Perhaps the most classic Deere tractor series was the popular *"poppin-Johnny,"* or *"Johnny popper"* 2-cylinder models in production from the 1920s until the 1950s (Sanders 1996). The Model D was originally introduced to the market in 1924 with 465 cubic inches of displacement and 27 belt horsepower (Bhp); the final version was introduced in 1940 with a whopping 501 cubic inch displacement and 38 Bhp. Just as the Fordson F became emblematic of early tractor production, the traditional John Deere green *"poppin" Johnny"* became synonymous with American tractors throughout the world.

The Hart & Parr Co. was established by Charles W. Hart and Charles H. Parr in Charles City, IA. Their initial work in internal combustion engines commenced in 1895, and by 1902 they had built their first tractor. By 1905 they had the distinction of being the first company in the United States devoted exclusively to tractor manufacture. The advertising manager at Hart & Parr is given credit for coining (in 1906) the word "*tractor*" to replace the more cumbersome *"gasoline traction engine"* (Sanders 1996; Gray 1975). In 1929 Hart & Parr was one of four companies merging to form Oliver Farm Equipment Company (Letourneau 1993; Sanders 1996). Oliver was, in turn acquired by White Farm Equipment Company in 1960. After a series of mergers and change of ownership, White-New Idea was acquired by AGCO who retained the White name through continued tractor manufacture as White Tractors and implement manufacture as White Planters (Sanders 1996; Gay 1997; AGCO 2001).

The J. I. Case Company is important to tractor development history for reasons similar to those of John Deere (Letourneau 1993, 1997). Jerome Increase Case established his firm in 1842 to manufacture threshers and other agricultural implements. In contrast to Deere, however, Case became an early and important player in the manufacture of steam engines starting in 1869, and ultimately steam traction engines

(1876-1924). Tracing Case history and products is useful in understanding not only the progress of Case, but also Case's place in the industry as a whole (Erb and Brumbaugh 1993; Case Corporation 2001). Though acquired for some time by such companies as Kern County Land Company and Tenneco, Inc., Case is now independent again, and is currently the second largest manufacturer of farm equipment in the country.

Current product lines and corporate history of Allis-Gleaner's (AGCO) brief, but dramatic rise from startup to achieve domination through acquisition of the agricultural equipment market provides additional insight into the maturation process of the tractor industry (AGCO 2001). AGCO had its roots in the agricultural slowdown of the mid-to-late 1980s. The venerable Allis-Chalmers Corp. found itself too heavily leveraged and went through a massive restructuring. When this restructuring failed to rectify the problems faced by the company, it went out of business, closing its West Allis plant. The agricultural equipment business was sold to Klockner-Humbolt-Deutz (KHD) of Cologne, Germany. KHD formed an American company, Deutz-Allis, as the operating entity of the former Allis-Chalmers. When KHD encountered its own financial difficulties, it sold Deutz-Allis to a management buyout group in 1989, who then started operations as Allis-Gleaner Corp. or AGCO in 1990. The new entity immediately set out on an acquisition program, acquiring some 17 tractor and agricultural implements companies. Gross revenues of $200 million in 1990, quickly expanded to $3.2 billion by 1997.

Thus the industry went from pioneers in the farm implements business (J. I. Case, John Deere, etc.), to pioneers in tractor development (John Froelich, Charles Hart, Charles Parr, Meinrad Rumely, etc.), to consolidation of the industry by acquisition

(Advance Rumely by Allis-Chalmers, Waterloo Gasoline Traction Engine Co. by John Deere, etc.), to merger (Oliver Chilled Plow Works, America Seeding Machine Company, Nichols & Shepard Thrashing Machine Company, and Hart & Parr Company to form Oliver Farm Equipment Company), to a conglomerate, AGCO, established solely for the purpose of acquiring agricultural implement and tractor firms, and having no contact with agriculture other than its corporate goal.

Establishing Performance Standards

Early on, the various tractor manufacturers were guilty of flagrantly overblown claims concerning the power delivered and capabilities of their products (Wendel 1993). This problem manifested itself so early that by 1908 a field tractor test was instituted at the Winnipeg Industrial Exhibition (Gray 1975). A series of characteristics, including fuel consumption and field performance, were measured with a point system used to rate the entrants. The *"Hauling Demonstration"* and the *"Plowing Competition"* formed the basis for the ratings. This field test was continued through 1913 until lack of interest by both manufacturers and the public caused its cancellation. During the ensuing years a series of tests were supported by the American Association of Agricultural Engineers, ASAE, and various other organizations. The federal government also considered involving itself for a time (Gray 1975).

In Nebraska the problem of tractor performance was a serious issue (Wendel 1993). Wilmot F. Crozier, having returned to farming after a career in education, had trouble with a new tractor not performing as advertised. On the other hand, when he purchased a used Advance-Rumely OilPull he found it to exceed specifications. From this experience, coupled with Crozier's former membership in the Nebraska legislature, came the idea of mandatory tractor tests sponsored by the state of Nebraska. Crozier, with the help of L. W. Chase, formerly with the University of Nebraska, prepared the appropriate legislation and sponsored its enactment on July 15, 1919. It was fashioned as:

> . . . *an act to provide for official tests for gas, gasoline, kerosene, distillate or other liquid fuel traction engines in the state of Nebraska, and to compel the maintenance of adequate service stations for same.*
> (Wendel 1993, 8)

Chase then returned to the University of Nebraska and became one of the founding fathers of the testing laboratory. Test No. 1 was completed on April 9, 1920 on a Waterloo Boy Model N, 12-25. Today, as in 1920, a series of standardized tests are performed on a tractor in order to measure its performance against a neutral yardstick, eliminating the human element, ambient atmospheric, and soil conditions in the testing. Quoting Prof. Chase: *"if a tractor fails to meet the manufacturer's performance claims, it is the fault of the tractor and not the yardstick."* (Wendel 1993, 9)

The standardized tests are identified as Tests A through K (Table 4)

From the start of testing in 1920 through 1984, a total of 1551 tests were performed. For purposes of this thesis, tests through 1955 are considered, through and including test number 570.

TABLE 4
INDIVIDUAL NEBRASKA TRACTOR TESTS

Test	Nature of Test
A	A "limbering-up test" allowing the manufacturer to ensure that a new unit is in proper adjustment and performing normally
B	The 100% maximum belt test designed to check and establish the belt horsepower rating Today the PTO is used rather than the belt.
C	The operating belt test allows a carburetor adjustment that is leaner than that of test B This setting is generally specified by the manufacturer as providing the most practical performance under general purpose use Today the PTO is used rather than the belt
D	This one-hour test is known as the "rated belt test " It is designed to determine if the tractor is capable of carrying its rated load on the belt and to establish a fuel consumption record along with other operating data Today the PTO is used rather than the belt
E	Known as the "varying-load test," the object is to determine fuel consumption and governor control under varying loads during six twenty-minute testing periods. The tested loads include rater load, no load, maximum load, one-half load torque, one-fourth load torque, and three-fourths load torque.
F	The 100% maximum drawbar test is designed to check and establish drawbar horsepower rating It is performed in the manufacturer's "rated" gear
G	This operating maximum drawbar test is repeated in all forward gears to determine the maximum horsepower developed in each with the engine operating at rated speed at ambient temperature and barometric pressure.
H	A ten-hour endurance test to determine whether the tractor is capable of pulling its rated load continuously and to determine a fuel consumption record on drawbar work
J	This test is performed using the operating carburetor setting, but with all added weight removed, this indicating the effect of weight removal on tractor performance
K	This test is performed using the operating carburetor setting. The object is to determine the effect of using smaller wheels and tires on the tractor's performance

(Wendel 1993, 9-11)

Measures of Power and Efficiency

In the United States the standard measure of energy applied to the powering of equipment and vehicles is the horsepower. By definition:

1 hp = 550 ft-lb/sec
= 33,000 ft-lb/min
= 1,980,000 ft-lb/hr

Where: 1 ft-lb/sec = the work required to move (lift) one pound of mass one foot in one second

Internal combustion engines used in automobiles and other vehicles are generally rated by the amount of horsepower delivered, referred to as brake horsepower, Bhp. In this definition:

$$Bhp = 2 \pi d n W / 33{,}000$$

where: d = distance between the shaft center and the bearing point of the brake arm in feet
n = revolutions per minute of the brake shaft.
W = net weight on the brake arm in pounds

(Salisbury 1950)

Unfortunately, the Bhp value provides little information about the amount of actual work a vehicle and especially a tractor can accomplish in the field under loading. Since early tractors were used extensively for driving external implements, as thrashers, the power delivered directly off the crankshaft to a drive pulley (and thence to a leather drive belt) was referred to as belt horsepower and is used more or less synonymously with Bhp.

Further, while either the brake or belt horsepower definitions are useful, the Bhp gives no indication of the power actually delivered to the drawbar – the point at which trailing implements are attached to the tractor. The loss of power between Bhp and drawbar hp is attributable to mechanical inefficiencies in the transmission and clutching systems, the power required to propel the tractor, and friction losses between the drive wheels of the tractor and the ground. Reference to Bhp vs. drawbar hp is generally expressed as dd/bb or dd-bb where dd is the drawbar hp and bb is the brake horsepower. A rule of thumb for early tractors would indicate that drawbar hp was generally half of the Bhp. Hence the Farmall in 1931 was rated at 9.35 drawbar hp and 18.03 belt horsepower indicated as 9/18 or 9-18 (Letourneau 1993). As time has passed, enhanced technology such as the pneumatic tire has allowed the drawbar hp to inch up much closer to the Bhp.

An innovation introduced by International Harvester in 1921 on its 10-20 and 10-30 models was the power takeoff (PTO). Originally developed in France in 1905, the PTO allows the tractor to provide power directly to a trailed implement via a drive shaft. Previously, trailed implements were pulled via the drawbar and powered by a bullwheel in contact with the ground. The PTO transfers power through the transmission to a splined shaft (rotating clockwise when viewed from the rear) which may then be connected to the trailed implement with a matched connection. This innovation required yet another measure of horsepower available for productive work: the PTO horsepower.

To clarify the various references to horsepower, the following definitions are provided (Table 5). These definitions were presented in a 1965 American Society of Agricultural Engineers (ASAE) technical paper by H. J. Slothower, Product Engineer, International Harvester Co.

The Society of Automotive Engineers (SAE) formula is a simplification of the indicated horsepower. It assumes that the mean effective cylinder pressure is 90 pounds per square inch, that the piston speed is 1,000 feet per second, and that the mechanical efficiency is 75 percent (Larsen 1981).

Equivalent Costs

Since the cost represents an economic barrier to the diffusion of the tractor, and the value of currency changes over time, currency standardization is important to place historical costs in modern day terms. This allows a consistency in examining relative costs during different periods (Economic History 2001). For instance, a Fordson F purchased in 1918 for $785 would have an equivalent cost of $8,980.84 in year 2000

TABLE 5
HORSEPOWER DEFINITIONS

Horsepower Type	Definition
Indicated Horsepower	That developed within the cylinders of the engine This will be high These results are not often quoted in advertisements.
Gross Horsepower	The power measured at the flywheel of a bare engine or stripped engine not installed in a tractor In this case the engine is equipped with only parts needed to make the engine run.
Net Horsepower	The power obtained at the flywheel while the engine is equipped with all the accessories needed to make it operate by itself
Belt or PTO Horsepower	The measured power obtained at the tractor power take off or PTO The PTO or belt tests made during the Nebraska tractor tests do not reflect any corrected results but are only observed results
Drawbar Horsepower	The power available at the drawbar of the tractor to pull equipment The Nebraska drawbar tests are only observed results; no corrections are made for temperature, humidity, barometric pressure or wheel slippage.
Peak Horsepower	The highest horsepower developed without any speed limitation. These runs are often made during a very short time.
Maximum Intermittent Brake Horsepower	Considered the maximum saleable horsepower and usually is used when referring to power units
Continuous Brake Horsepower	Ratings are those recommended for operation under continuous conditions. This is used mainly for power unit terminology
SAE Horsepower	Formula intended to determine the approximate brake horsepower of an engine. $hp = d^2 n/2.5$
where	d = the bore of the cylinder in inches n = the number of cylinders

(Salisbury 1950)

dollars. Note that the Fordson F entered in the Nebraska tractor tests in 1920 produced 18.16 belt horsepower (horsepower at the flywheel), but only 9.34 drawbar horsepower. This is about the same as a garden tractor of today. Thus the farmer of 1918 paid the equivalent of $9,000 for a tractor providing no more capability than a $1,500 unit today.

Summary of Prerequisites and Development

As presented here, development of the tractor was possible only after a set of sociological, geographic, and technological prerequisites were in place (Table 1).

Provision of these prerequisites began with advancements during the Baroque period and coalesced during the Industrial Revolution. Once manufacture of the tractor began, the technological advances and the maturation of the companies in the industry are inextricably intertwined in examining how tractors came to be setting on the showroom floor, with what features, and at what cost for the adoption decision by the farmers of America.

THE DIFFUSION PROCESS

It is asserted here that even after the development of the tractor had progressed to the point of innovative farmers experimenting with a tractor, its ultimate diffusion was heavily influenced and at times dominated by local, national, and world events of the times acting as both incentives and barriers. Thus, information on the diffusion process must come from a variety of sources, addressing individually the economics (and particularly agricultural economics), domestic and world politics, societal patterns from the past, and other exogenous factors impinging on the adoption decision of the individual farmer.

Classical works on diffusion treat the phenomenon as an exercise in the application of academic theory to real world events. Therefore, the study here must, perforce, ground itself in theory. Perhaps the most recognized geographical author on diffusion is Torsten Hägerstrand (1967). This work, translated from the original Swedish by Allan Pred of the University of California at Berkley, presents two significant components of Hägerstrand's work: a descriptive and inductive model of the stages of spatial diffusion of innovation, and a series of Monte Carlo simulation models. This work is referenced as appropriate in examining the particular circumstances of diffusion of the agricultural tractor.

Gould (1969) provides an American update to the work of Hägerstrand while also providing useful techniques such as a generalized equation for the S-curve (logistic) of innovation adoption. Rogers' (1995) much newer work on diffusion of innovation provides the structure for a significant portion of development of the diffusion aspects of the thesis; including his characterizations of adopter categories, and the characteristics of individual innovations relative to diffusion.

Setting the tone of the times in which diffusion initiated, Bertrand Russell (1953) provided a philosophical framework for consideration of a significant technological advance having far-reaching societal impact. As a philosopher, Russell was somewhat ambivalent toward progress through technology as it might impact mankind's pursuit of daily life. This ambivalence set the tone of Russell's interpretation of the status of society during the period in which tractor diffusion progressed through its early stages. With different phraseology, Russell addressed such topics as (in Rogers' terminology) compatibility. He called this *"science and tradition."* To emphasize the difficulty of overcoming tradition and orthodoxy he noted (1958, 9):

> *When Galileo's telescope revealed Jupiter's moons, the orthodox refused to look through it, because they knew there could not be such bodies, and therefore the telescope must be deceptive.*

He examined some of the negative twists of technology's progress by citing the U.S. Plantation South, where slavery was on the wane by 1787 (it was outlawed in the North and West). Good for the economy, but bad for the institution of slavery, Eli Whitney invented the cotton gin in 1793. Suddenly a slave could clean fifty pounds of fiber in a day vs. the one pound of pre-gin days. Demand for cotton soared as the price went down as a result of this *"laborsaving"* device. Russell concluded that one result of the gin was the U.S. Civil War, which quite possibly would not have occurred had the cotton industry remained unscientific. Finally, in examining man's future role in a society *"enriched"* by the scientific technique, Russell expressed one of his root concerns (1953, 60):

> *Scientific technique, by making society more organic, increases the extent to which an individual is a cog; if this is not to be evil, ways must be found of preventing him from being a mere cog. This means that initiative must be preserved in spite of organization.*

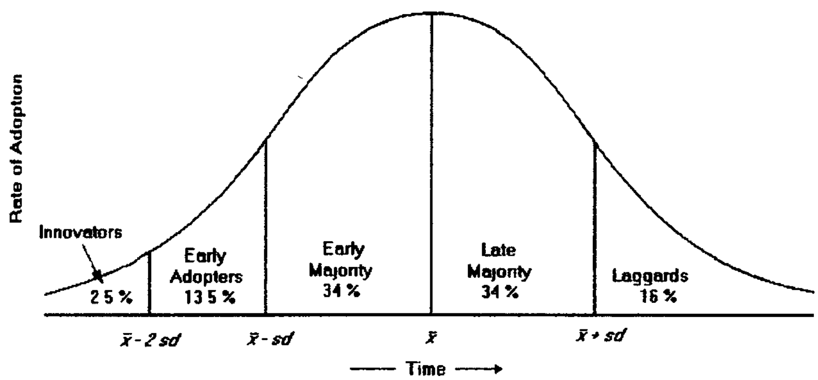
It is argued here that the presence of the perfect competition model for marketing agricultural goods in the U.S. is a prime reason why the farmer, with the newfound productivity via the tractor, and other agricultural implement innovations, has retained an individualism in the face of ever-increasing scientific techniques.

Classical Normal Distribution and S-Curves of Innovation Diffusion

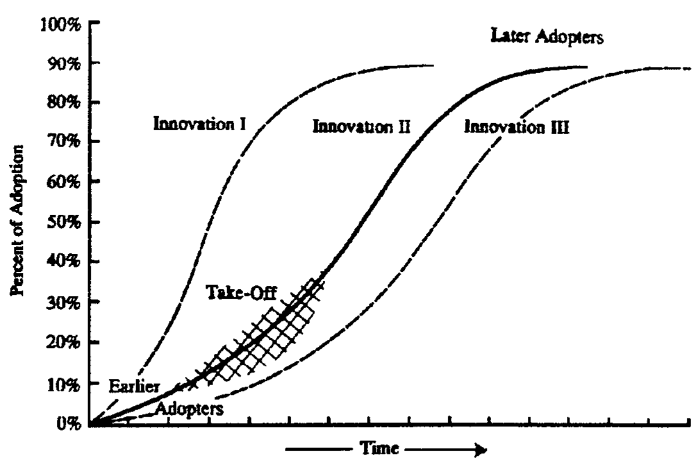
Two curves form a portion of the classical discussion of diffusion of innovation and are routinely referenced throughout the literature: the normal distribution curve showing the rate of adoption over time, and the S-curve showing the cumulative adoption of an innovation over time (Rogers 1995; Gould 1969). Ryan and Gross (1943) note that application of the normal distribution and S-curves was popularized by F. Stuart Chapin in his book *"Cultural Change"* (1928). Pemberton (1936; 1937) makes the same attribution in his elaboration on the subject; applying the concept to such diverse adoption phenomena as countries adopting the postage stamp to adoption of compulsory school laws amongst the then 48 states.

Relationship of the Normal and S-Curves

The two curves under consideration are shown in Figures 4 and 5 in generalized form. Rogers (1958, 1995) provides a temporal framework of evolving adopter



(Rogers 1995 262)
Figure 4. Normal distribution curve of incremental adoption.



(Rogers 1995 11)

Figure 5. Multiple S-curves of cumulative adoption.

categories useful in investigating the unfolding process of diffusion of the tractor. He argues that the adopter categories must satisfy three criteria. They must be exhaustive so as to include all potential members of the adoption population; they must be mutually exclusive so that each adopter may unambiguously be assigned to a single category; and they must be derived from a single classificatory principle. Farmers adopting tractor technology meet these criteria. Figure 4 shows Rogers' five categories of adopters with the accompanying percentages for each category. He points out that analysis of adopters is dependent on: the researcher's decisions concerning the number of adopter categories to be considered, on the percentage of the normal distribution system to assign to each of the categories, and on the method of definition (statistical or otherwise) to be used in defining the categories.

Gould (1969) chooses to omit the early adopter category used by Rogers. This allows definition of the remaining four categories to be defined symmetrically around the mean point of the curve in which a theoretical 50 percent of the potential adopters are defined as innovators and early majority while the latter 50 percent are defined as late majority and laggards. If the rate of adoption of an innovation is rapid, the amplitude of the curve will be large relative to delta *t* – with the elapsed time to achieve any given percentage of adoption reduced. If adoption of an innovation is slow, the amplitude of the curve will be small relative to delta *t* – with the elapsed time to achieve a given percentage of adoption increased. The rate of adoption within each of the adopter categories may vary from the rate of the adjoining adoption categories, resulting in a positive or negative skew to the distribution curve. This can result if an innovation is rapidly adopted by innovators, early adopters and possibly early majority then encounters a slowdown as late majority and laggards move more cautiously or slowly to adopt the innovation – positive skew. Conversely, a negative skew may result if the innovators, early adopters, and early majority adopt at a leisurely pace, followed by rapid acceptance and adoption by the late majority and laggards.

Rogers raises the issue of why the rate of adoption of a technological innovation may be expected to follow a normal distribution. He points out that it has been observed that human traits tend to follow such a pattern – specifically noting physical characteristics such as height, performance on tests, etc. He then concludes that it is not unreasonable to expect a human variable, as the acceptance of technological innovation, to follow a similar pattern. Rogers (1958, 349) then comments that reasons for a positive or negative skew are not necessarily obvious, but hypothesizes: *"there seems to be some evidence that at least two factors are relevant: the intrinsic nature of the practice, and the locale of the study."* Rogers (1995, 347-9) finally comments that: *"Further research is needed to determine specifically why some adoption curves are normal and some are not."* This thesis subsequently examines the exogenous forces asserted to affect adoption of the agricultural tractor – associating these events of the time with the performance of the various adopter categories during their decision process.

The S-curve in Figure 5 shows the cumulative adoption (frequently expressed as a percentage of the whole) experienced by the innovation at any point in time. The normal distribution and S-curves are intimately related; the S-curve results from integration of the area under the normal distribution curve over some time period. Hence:

$$A = \int f(t)\, dt$$

Where: *A* is the adoption achieved as a result of integrating some *f (t)* over time *dt (i.e. t to t+1)*. *f (t)* represents the shape of the particular normal distribution curve under consideration.

Alternatively, Pemberton (1937) refers to the resulting S-curve as the ogive of the normal distribution curve.

The shape of the resulting S-curve, then, will reflect the characteristics of the adoption process of a particular innovation as defined by the normal distribution expression. Figure 5 illustrates this phenomenon by indicating three innovations, each with its own S-curve having a different slope and hence differing times to achieve adoption. Here Innovation I would have had a greater amplitude relative to time than the other two innovations, and Innovation II would have had a greater amplitude relative to time than Innovation III.

Obviously the x-axis will reflect the same elapsed time for both the normal distribution and S-curves. If the normal distribution is positively skewed, the S-curve will reflect this characteristic with a short initial tail, followed by a steeply sloped mid-portion leading to the mid-point (50 percent adoption) of the innovation. If the normal distribution is negatively skewed (drawn out adoption by late majority and laggards) then the S-curve will broaden out with an extended final tail indicating the extended time lapse for adoption relative to that of the earlier adopters. In either of these skew situations, the mid-point of the x-axis will no longer correspond to the 50 percent point of the y-axis.

Logistic Definition of the S-Curve

Gould (1969) and Morrill (1968) describe the S-curve as logistic in nature. Gould presents an equation defining the curve in mathematical terms:

$$P = U/(1 + e^{(a-b*T)})$$

Where:

P defines the proportion of adopters having acted at any point in time – generally expressed as a percentage. Grubler (1996) notes that the inflection point occurs at $P/2$ when dP/dt approaches max.

U is the upper limit of the curve to be considered. If examining the full range of the S-curve, this becomes a constant 100. If, however, the potential adoption does not extend to 100 percent saturation, the U value may show less that 100 percent.

e is the natural log with a constant value of approximately 2.7183.

a and b are constants related to the particular adoption situation. a controls the height above the x-axis at which adoption is shown to commence. b determines the rate of rise (slope) of the curve.

T indicates some period of elapsed time expressed in consistent units, as days, weeks, months, years, decades, centuries, etc.

a and b, then are parameters representing the individual innovation under consideration. Gould chooses as an example $a = 3.0$ and $b = 1.0$. He notes that at time $T = 0.0$, the denominator of the expression is reduced to $1 + e^3$ and that P then is approximately 100/21 or approximately 5.0 – indicating that 5 percent of the potential adopters had already opted for the innovation at the start of the adoption analysis period. Thus, a is inversely proportional to the percent of adopters at the initiation of the adoption period. As T becomes larger, the value of the exponent is reduced. In this example, when $T = 3.0$, the exponent reduces to zero, and e raised to the zero power is 1.0, the denominator of the expression becomes 2.0 and $P = 100/2 = 50$ percent. Finally, as time T continues to increase, the exponent ultimately becomes negative, reducing the value of e raised to the now-negative exponent to near zero, leaving P = 100/1, at which time adoption would be complete. Thus, the larger the value of b, the faster the $b * T$ product will increase and the faster the exponent of e will become negative – having the effect of increasing the slope and decreasing the time to saturation. By becoming familiar with the characteristics of the S-curve as specified by *a* and *b*, one could theoretically define any diffusion process by specifying these parameters to whatever accuracy has meaning for the problem at hand.

While interesting as an intellectual exercise, and perhaps useful as a point of departure for a specific diffusion examination, it is important to note that expressing the S-curve in this fashion as logistic does not allow for any skew in the normal distribution curve. In this mathematical expression, the halves of the curve pivoting about the 50 percent axis are *defined* as mirror images of each other. In the real world of diffusion of innovation, this is not likely to happen. In the case of the agricultural tractor, considering the time period involved and the familial, societal, economic, and political/governmental exogenous forces (including boom, depression, drought, and war) of the diffusion process encompassed by the period, the S-curve logistic equation has little practical application. Agnew (1979, 366) seems to support this thesis. He notes that:

> *The logistic curve must be unambiguously identified with the specific theory. Yet curve fitting is a notoriously indeterminate procedure. . . . Further, on what basis can we infer, as Amedeo and Golledge suggest, that a particular curve or pattern is explained by a specific theory represented by the logistic growth model? In truth, there is little at all. Many theories might be invented from which a particular curve would follow deductively. Curve fitting therefore cannot provide a satisfactory means of discovering and evaluating an explanatory theory.*

Grubler (1996, 41) takes a slightly different approach, using the logistic curve as a trend line from which specific studies may digress, referring to *P(t)* as : *"the sigmoidal growth through time of a population or process."* (Pemberton 1937, 556)

Superposition of the Normal and S-Curves

Chapins' (1928) first example of the relationship between the normal distribution and S-curves nicely juxtaposes with the subject of this thesis. He traces the innovations related to the sulky plow during its period of prominence. During the period 1855-1923, this plowing innovation achieved much popularity. It was a riding plow involving a tri-cycle wheeled arrangement, and pulled by a team of draft animals. One wheel tracked on unplowed land while the remaining two wheels tracked in the furrow.

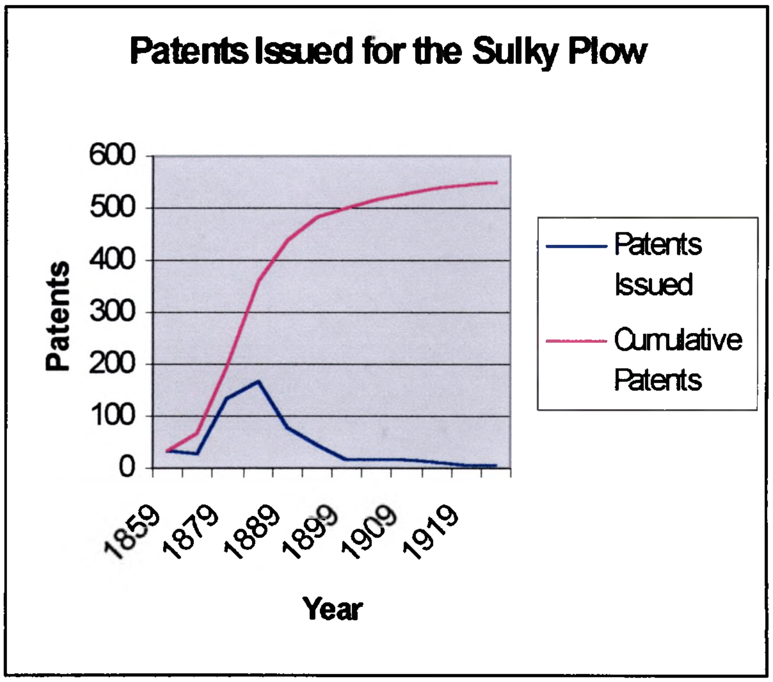
The popularity of this innovation in plowing is indicated by the number of patents directed at improving on the original design. For purposes of this thesis, patents issued are considered a surrogate for market penetration of the sulky plow, whereby the positive skew of the normal distribution curve implies a rapid market penetration with manufacturers vying for the available market with new features. As the market became saturated, and the ultimate obsolescence became apparent due to competition from the tractor, manufacturers ceased chasing sunk costs or investing new money in additional innovations as reflected by patents issued.

Chapin traces the issuance of 549 patents during this period. Table 6 and Figure 6 track the progress over the years of patents issued relative to the sulky plow. The figure, more than the table, indicates both the relationship between the normal curve of incremental adoption (in this case patents issued), and cumulative adoption (in this case

TABLE 6
PATENTS ISSUED FOR THE SULKY PLOW

Year	Patents Issued	Cumulative Patents	Year	Patents Issued	Cumulative Patents
1855-59	35	35	1895-99	16	499
1870-74	29	64	1900-04	16	515
1875-79	131	195	1905-09	15	530
1880-84	164	359	1910-14	11	541
1885-89	80	439	1915-19	5	546
1890-94	44	483	1920-23	3	549

(Chapin 1937, 359)



(Chapin 1937, 360)

Figure 6. Normal distribution and S-curves of patents issued relative to the sulky plow, 1855-1923.

total patents issued). Note that the figure depicts a significant positive skew in favor of early patents issued. This would indicate a rapid acceptance of the sulky plow and acknowledgement on the part of developers (here agricultural machinery manufacturers) of the validity and expected and achieved popularity of the sulky plow. Following a period of rapid development, the tail of the S-curve extends from a period of approximately 1900 until the termination of the study in 1923. Two events would have occurred to influence this pattern. First the innovations from the 1850s until the 1920s encompassed the practical evolution of the sulky plow. Secondly, the introduction of the internal combustion engine powered tractor starting in the first decade of the twentieth century initiated the obsolescence of the draft animal powered plow – regardless of its improvement over previous plowing technology.

The same relentless advance of the gasoline traction engine during this period also marked the end of the steam traction engine era. J. I. Case completed its last steam traction engine on September 28, 1924 (Erb and Brumbaugh 1993) – the last U.S. steam traction engine manufacturer to cease such operations.

State of the Country During the Diffusion Period

To set the stage for agricultural tractor diffusion, (1880-1954) the state of the country and the life of the farmer on the eve of gasoline traction engine introduction in the 1880-1907 timeframe must be placed in perspective.

Entering this period the nation was still bitterly divided over the Civil War; reconstruction was very recent history; and while slavery had been abolished, the number of African-Americans in the old Confederacy remained (in the form of freedmen) approximately the same as before the war. Freedmen were nominally citizens, but their life as sharecroppers and tenant farmers did not differ significantly from their just-ended slave days when they were considered an energy source rather than citizens (Gunlogson 1957).

Population

The population of the United States was growing and partially shifting its location. While the area of the current contiguous states was the sole property of the U.S., two territories (Oklahoma and New Mexico) were not yet states. At 75 million people, there was one quarter of the number in the contemporary population. By 1950 the population had doubled to 150 million. While there was significant decline in the birth rate from the turn of the century to the 1930s, the period of the Great Depression saw historical lows as families postponed having children in anticipation of better times.

Various decades of the period experienced population shifts that at times acted as incentives or barriers to the diffusion of the tractor. In 1900 the Rural Heartland comprised 15 percent of the nation's population (Historical Census Data 2001). The Rural Heartland is defined by the Federal Reserve Bank of Kansas City as encompasses the states of Oklahoma, New Mexico, Missouri, Kansas, Colorado, Iowa, Nebraska, Minnesota, South and North Dakota, Wyoming, and Montana (Federal Reserve 1996). By 1950 this percentage had dwindled to 13 percent with the region experiencing only a 70 percent growth as opposed to an increase of 100 percent for the nation as a whole.

Perhaps the most noteworthy decade was 1900-1910. During this period the Rural Heartland experienced a growth rate half again that of the nation as a whole and the era of the steam traction engine was in its ascendancy. The Rural Heartland was, for the most part, settled by 1910. Thus the people were in place to take advantage of the enhanced agricultural equipment developed during the 19th century, and the enhanced power potential available through the agricultural tractor.

World War I enhanced demand for Rural Heartland cash crops (principally wheat and corn). The result was that plowed acreage of the area doubled during the 1910-1920 period (Pripps and Morland 1994) even as labor hours required to harvest a unit of either crop (Figures 2 and 3) continued to drop (USDA 2001). The agricultural depression of the 1920s depressed population growth, with the Rural Heartland increasing by only 7.8 percent during the 1920s as compared to 16.2 percent for the nation as a whole.

With heavy emigration and little immigration during the decade of the 1930s, population growth in the Rural Heartland essentially stopped. Between 1930 and 1940, the population in the region increased by only 430,000 or 2.25 percent (Historical Census Data 2001). While the population remained stable, however, landholdings became larger with better capitalized landowners capable of buying tractors and realizing a decent return on their investment due to economies of scale.

Thereafter the rate of growth declined until by 1950 the rate of growth had slowed to 4.7 percent – one-third the rate of the U.S. as a whole for the decade of the forties (Historical Census Data 2001).

Transportation

Progress on the transportation network (some have called it a revolution) had transformed the face of the United States, and the scale and tempo of industry. Toll roads, canals, steamships, and railroads were allowing raw materials to be assembled and finished goods to be distributed faster and more economically than ever before. The golden spike at Utah's Promontory Point was put in place in 1869 – linking the east and the west together via railroad (Sanders 1996). By 1907 the nation's railroad network was essentially in place with 237,000 miles of track. Canada provided an additional 22,500 miles and Mexico contributed an additional 13,600 miles of track to the North American network (*The Encyclopedia Britannica*, 11th ed., s.v. "railroads").

Communication

Rogers (1995, 10) states as part of his fundamental definition of diffusion that an *"innovation is communicated through certain channels over time."* Literacy in the United States was not a problem. The 1930 census boasted a national literacy rate of 96.5 percent. Lower percentages were reported in the Deep South with its heavy African-American population, plus New Mexico with its heavy native-American and Spanish-American populations. In the Rural Heartland adult literacy ranged from 90.1 percent in New Mexico (see above) to 99.4 percent in Iowa, with a 98.4 percent average for the area as a whole, well above the national average (Historical Census Data 2001). Thus, printed matter in the form of USDA farmer's bulletins, newspapers, farm gazettes and advertising materials presented a viable means of information dissemination when it was possible to get the printed matter into the hands of the farmer. Marti (1980, 28) writes:

> *The Indiana edition of the Prairie Farmer differs from the New York Review of Books perhaps most conspicuously in its fertilizer advertisements and style of humor. On the other hand, it resembles the New York Review of Books in its regular efforts to be serious and in its apparent conviction that advanced knowledge is to be obtained from people in colleges.*

He traces the progress of the farm digests (gazettes) from the 1790s to 1850s; noting that (1980, 30):

All of the journals were interested in manures, new crops and implements, and improved livestock. The American Farmer took special pride in being the first publisher of Edmund Ruffin's 'Essay on Calcareous Manures,' but they were all interested in means of restoring soil fertility.

However, the state of communications media was still relatively primitive – at least by modern standards. As late as 1930, when 90 percent of urban dwellers had electricity, only ten percent of rural dwellers were so equipped (Rural Electrification 2001). The moving force behind the electrification of America's farms was the Rural Electrification Administration, REA, whose creation and mission were so important to farmers during its formative years starting in 1935.

For the rural dweller of the first half of the 20th century, few channels of communication could be more important than that of electrification and implicit access to radio (Cavert 1956). Electricity provided power for refrigerators to replace iceboxes, power for irrigation pumps to supplement windmills, power for water well motors allowed replacement of the hand-cranked water well and ushered in the era of indoor plumbing, and power for milking machines to supplement the hands of the farmer. As well, perhaps, electricity provided lighting to read by as a replacement for the kerosene lantern and provided power for the radio. More reading time allowed the accumulation of more and better information on the latest farming methods and available technology. The radio (and much later television) provided up to the minute information on market status, prices, and the weather (Jones 1963, 1967). However inadequate the weather forecasts provided by radio may have been in the age before weather satellites and computerized hemispheric modeling systems, they provided the farmer with information beyond that of his or her own personal observation.

The Steam Traction Engine Era

As the Industrial Revolution reached its climax, so to did the age of steam power, most particularly for ships and railroads. Separate from the internal combustion engine powered tractor, but an integral part of the tractor diffusion process was the steam traction engine. This machine was an enabling force for change as Erb and Brumbaugh (1993, 42-3) state:

> *Steam power made large-scale farming possible, without it the bonanza era could not have happened. The large prairie-breaking steam plows and threshers that separated thousands of bushels a day would not have been developed without steam to power them.*

The use of the steam traction engine as the motive power for both plowing and threshing also had a catalytic effect on demand when the opportunity for the lighter, more versatile internal combustion engine became available. All this was accomplished with the manufacture of only 83,824 units. At the peak of their popularity in 1910, a mere 72,000 units were in use (in 1910 there were 119,000 farms in Montana, Wyoming, Colorado, and New Mexico alone (Gates 1977)).

In the process of steam traction engine development, much progress was made in the design and manufacture of clutches, gearing, wheels, steering, and frame components (importantly including spring mounting of axles). It was natural as the internal combustion engine began replacing the steam engine that a simple replacement of steam with internal combustion engines on the old chassis was made. Thus the development of the steam traction engine not only acted at a catalyst for development, it enabled the rapid placement of internal combustion powered tractors in the fields (Erb and Brumbaugh 1993).

Conflict of Technological Preference: Animals vs. Tractors

The shift, however, from horse to tractor was not totally without opposition. Certain groups of traditionalists clung to the belief that there were advantages of horses over tractors. Animals provided fertilizer for the fields, hides for leather, bones and hooves for bone meal. And there was the affectionate bond between farmer and animal as they toiled together. Along these lines there was an added advantage to the horse. There were no new models, and no technological change (some modifications to tack not withstanding). Once animal husbandry and handling was learned as a youth, the knowledge remained with one for life. With the tractor, on the other hand, there was an ongoing challenge to master new technology.

Many farmers initially scoffed at the tractor as labor causing rather than saving (Pripps and Morland 1998). However, there was one source of active dissent regarding the tractor coming from elements in the agricultural community having an interest in promoting the retention of horses on the farm. Ellenberg (2000) details the struggle between the pro-mechanization and pro-horse forces during the 1920s and 1930s, and each side's somewhat futile attempts to enlist the USDA in support of their cause. The two groups were represented by organizations where the members had a vested interest in the perpetuation of their viewpoint. On the horse side was the Horse Association of America (HAA) notably populated by veterinarians, farriers, breed association members, and grain marketers (all of whom had personal stake in the perpetuation of draft animals' supply of motive power in the field). Dinsmore (1922) representing the HAA, writes forcefully on behalf of large teams of horses to combat the pulling power of tractors. He proudly presents a diagram of a hitch for a twelve-horse team capable of pulling two tandem disk harrows cutting all hoof prints except on turns. Opposing this group was the Tractor and Thresher Department of the National Association of Farm Equipment Manufacturers. Each group was continually frustrated by their inability to entice the USDA to take a clear and unambiguous stand in their favor. This controversy raised questions that no doubt increased uncertainly in the minds of potential adopters and slowed the diffusion of the tractor. By the commencement of World War II, the argument had been rendered moot with a critical mass of adoption of the tractor having been achieved. This footnote to tractor diffusion shows how little the USDA inserted itself into tractorization, and how little a role the department actually played. Thus we have a rare instance where the government passed on the opportunity to influence farm policy.

Schlebecker (1977a, 652-3) however, argued that technological innovation on the farm was not possible without a solid governmental bureaucracy. He makes the point that:

> *Innovation in farming requires internal peace, adequate transportation, and a uniform currency. These in turn, if available on any appreciable scale, require a bureaucracy.*

Thus, while Ellenberg argued that the governmental department most involved in agricultural policy and oversight, the USDA, successfully (and correctly) remained above the tractor vs. horse debate, Schlebecker argued for a strong bureaucracy as a necessity for the same type of diffusion of innovation.

Ellenberg (1998) introduced yet another aspect to the economics of draft animal vs. tractor debate with his discussion of mule use in the Plantation South. His thesis rests on social and intellectual perceptions of the *"bond"* between African-Americans and the mule. Snow (1954) presents his personal experiences of a lifetime spent working mule teams, describing their unique personalities, propensities and physical strengths in supporting Ellenberg's *"bond"* theory. Ellenberg pointed out that only in the post World War II era as African-Americans left the south in significant numbers did the tractor make significant inroads. Kauffman (1993) focused on the *"principal-agent"* aspect of mule use. He pointed out that, for a variety of reasons, the mule is congenitally better able to cope with poor or ill treatment than is the horse. Therefore, since the landholder traditionally supplied the draft animals for the farms, the mule was the animal of choice in the post-bellum Plantation South where tenant farmers and sharecroppers were present in larger numbers than other parts of the country. Using this same rationale, selecting the mule over the horse, would have remained the same in delaying the shift to tractors. As the tenant farmer/sharecropper infrastructure disintegrated following World War II, the tractor would have become much more appealing to the large land holder (now working the land personally) who would have previously been hesitant to provide a tenant farmer/sharecropper with a tractor. Olmstead and Rhode (1988a, 1988b, 1994) provide details of individual aspects of the tractorization movement in other geographical parts of the country. They discuss the mechanization of California agriculture, the farm energy crisis of 1920, and the agricultural mechanization controversy during the inter-war years (see also Ellenberg (2000) as noted above).

Land and Farm Labor Reallocation

The transition to the tractor also had certain secondary effects as regards physical resources. Cavert (1956), discussing the technological revolution in agriculture, makes the point that the shift away from draft animals required a massive realignment of land allocation. Olmstead and Rhode (1994) detail the displacement of draft animals with tractors and the implications thereof. The number of horses on farms in the U.S. in 1910 was approximately 24 million. An additional 4.8 million head constituted the non-farm horse population. Allocating 3 1/3 acres per head, approximately 88.3 million acres of productive land out of 325 million acres (or 27 percent of the total) under cultivation were devoted solely to feeding draft animals. By 1953 the number of horses had dwindled to approximately 4.3 million, requiring 14.3 million acres for feed. So out of 349 million acres under cultivation in 1953, only 4 percent was set aside for draft animal feed. In the period 1910-1953, 74 million acres of feed acres became available for conversion to money crop acres.

The mechanization/tractorization movement affected farm population just as dramatically. Cavert (1956) notes that in 1910 total farm employment was 13.56 million, of which 10.17 million were family workers and 3.38 million were hired hands. By 1953 these numbers had shrunk to a total of 8.58 million total, with 6.65 million family workers and only 1.93 million hired hands. Thus in a span of 43 years there was a decline in total farm employment of 37 percent with a 43 percent drop in hired hands. This occurred while money crop acres under cultivation increased by 98 million acres. Such a massive reallocation of resources led to an overall change in farm operations policy and practice. Cavert discusses a series of managerial and technical reasons for the conversion to tractor power. He also lists and discusses seven such changes, including: more emphasis on management, a trend toward specialization, and a trend toward larger units. King (1929) had earlier made many of the same points though from a farm economics viewpoint rather than the agricultural history perspective of Cavert.

Economic Models and the Relative Advantage of Tractor Adoption

Ankli (1980) provided an economic model demonstrating that with the specific economic conditions of the early 1930s on the Corn Belt, it was advantageous for small-team horse farms to remain with the horse. A large-team horse farm was also better off remaining with horses. Only the middle-sized farm was positioned to take advantage of the tractor technology of the time. This apparent anomaly resulted from the economics of tractors vs. horses, whereby use of a tractor is fixed cost saving but variable cost consuming. Clarke (1991) presented her own economic model determining that most farmers were advised to convert to tractor power during the Great Depression of the 1930s, and that only the lack of money (partially alleviated by federal programs) prevented greater conversion to tractors during this period. Saloutos (1969), like Clarke, focused on the New Deal and Great Plains farm policy. However, his emphasis was broader in nature, identifying a wider range of federal programs and classifying them into short-term relief programs vs. longer-term support programs. His conclusion was that both types of programs aided and abetted the trend toward fewer but larger farms, as the number of farms in 421 counties of ten Great Plains states decreased by 39 percent in number while size increased by 99 percent. Lew's (2000) geographical interest was in the Canadian Prairies, specifically Saskatchewan. However, since the Great Plains soil and weather are unaware of the U.S./Canadian border, the farmers of southern Saskatchewan faced essentially the same economics as their neighbors in northern

Montana and North Dakota (Ankli 1977). Lew examined both Ankli and Clarke's models and concluded that the unpredicted, slow diffusion of the tractor during the 1920s and 1930s resulted from a flaw in their threshold models. He examined the volatility of wheat pricing vis-à-vis falling tractor pricing and enhanced tractor functionality to conclude that the lag was rational on the farmer's part. Lew then proposed a modified threshold model that included a factor for market uncertainty. In this fashion he was able to introduce into the model some of the external economics coupled with technological development and societal evolution as the number of farm hands working the land diminished. Oster (1999) considers this lag as a normal human reaction recognized as *"risk aversion."*

The Period of Diffusion

The diffusion of the agricultural tractor covered a period of approximately 75 years. During this period the traditions and practices of thousands of years of farm operations were altered irretrievably. The years involved major local, national, and world events or exogenous forces acting as both incentives and barriers to the adoption process. Thus, to examine the diffusion process itself, one needs to start with the state of technology and the state of the nation at the start of the process and track the events impinging, and sometimes contravening each other, on the process. The approach taken here is to chronicle the critical events of the period and track their impact via the concepts of diffusion theory as particularly expressed by Rogers (1995). His assertions regarding the nature of adopter categories (defined as innovators, early adopters, early majority, late majority, and laggards), and the characteristics of the innovation (relative advantage, compatibility, complexity, trialibility, and observability) are used as the vehicle for examination of the tractor during its diffusion period.

The Tractor as a Further Agent of Change

It is impossible to discuss the diffusion of the tractor without examining its consequences on the various segments of society. Examining some of the consequences of diffusion help close the feedback loop to both the purely diffusional aspects and to the developmental aspects of the total picture. This would include the daily impact and economics of America's farmers, urban dwellers, manufacturers, planners, and the bureaucracy. Consider; if the purchase and use of a tractor by the innovators had not provided a positive and salutary experience for those making the adoption decision, agricultural tractor diffusion would have descended into discontinuance, and we might remain today dependent on draft animals as the motive power of agriculture.

An easy way to get an overview of these consequences is to examine the significant events in agricultural development (not just of the tractor, but of all agricultural diffusion processes and events) in a chronological fashion. Such a presentation provides contextual significance to tractor development and diffusion relative to other major events of the period, and its contributions as an agent of efficiency (USDA 2001). For instance, in 1890 at the dawn of steam traction engine diffusion, 35-40 labor-hours were required to produce 100 bushels (2.5 acres) of corn with a 2-bottom gang plow, a disk and peg-tooth harrow, and a 2-row planter. By 1930 with more than 2.25 million tractors manufactured and sold, only 15-20 labor-hours were required to produce 100 bushels (2.5 acres) of corn with a 2-bottom gang plow, a 7-foot tandem disk, a 4-section harrow, and 2-row planters, cultivators, and pickers. The equipment listed and the manpower saved would not have been possible without the availability of an economical row crop tractor.

Cavert (1956, 19) comments that:

> *In contrast with the situation in 1910, or even in 1930, by 1955 mechanization has progressed to the point that a farm relying chiefly on horses is a fit theme for the Sunday supplement.*

He further elaborates on this theme by listing changes in requirements for successful farm operations as a result of mechanization. These include 1) more emphasis on management, 2) trend toward more specialization, 3) modern technology and land values, 4) favorable location, 5) more products with less labor, and 6) trend toward larger units.

Summary of the Diffusion Process

Development of an innovation is not important (other than perhaps as an intellectual curiosity) without diffusion. Diffusion of a technological innovation is not important without its having some consequences – no consequences, no reason for further development and diffusion. It could be argued that a zany new hairstyle could be developed and diffuse throughout the target population without creating any lasting impact, but we are only examining technological diffusion here.

The process of development is initiated at some historical point with the evolution of various prerequisites required for future development. Once the prerequisites are in place, development proceeds as a result of individual initiative and/or market demand. Starr and Rudman (1973, 364) refer to this process as *"societal resources"*, and *"societal expectations."* In the case of a significant technological innovation where a new industry is created, development is chronicled by the maturation of both the corporate players and the innovation itself.

When the innovation has advanced to the point of adoption, diffusion begins. Adoption of the innovation has two immediate results. First, it accomplishes the task for which it is intended. Second, it produces immediate consequences resulting from its accomplishments, and thus the feedback loops are activated. Once these results are in operation, the process will continue as a closed loop at various levels of activity in development, diffusion and consequences until such time as the innovation is rendered obsolete by a replacement innovation. Then a new development/diffusion/consequences cycle commences for the replacement innovation, and the former innovation passes into oblivion.

CHAPTER 3

METHODOLOGY

INTRODUCTION

Before a technological innovation can diffuse, the innovation must meet the expectations of the initial adopters. This thesis identifies a set of prerequisites required for development (Table 1), and relates them specifically to the agricultural tractor. With prerequisites in place, development itself can proceed. The thesis traces the development phase via the genealogy and model series offered for a selected number of representative tractor manufacturers. The diffusion model of this thesis centers on Rogers' (1995) diffusion theory. As applied here, the specific diffusion process is the agricultural tractor as it occurred from roughly 1880 until 1954. Once the diffusion process was underway, continued adoption by successive categories of adopters rested on the realization of the expectations by those having already made the adoption decision.

The literature review revealed/formulated that development is a process initiated by the evolution of a set of prerequisites (Figure 7). These prerequisites ultimately act as the foundation for the development effort of a new technological innovation. However, this evolution is somewhat of a random process in that by and large, the developer of a law, mathematical technique, engineering advancement, business policy or other prerequisite does not act with the vision that such effort will provide a prerequisite for

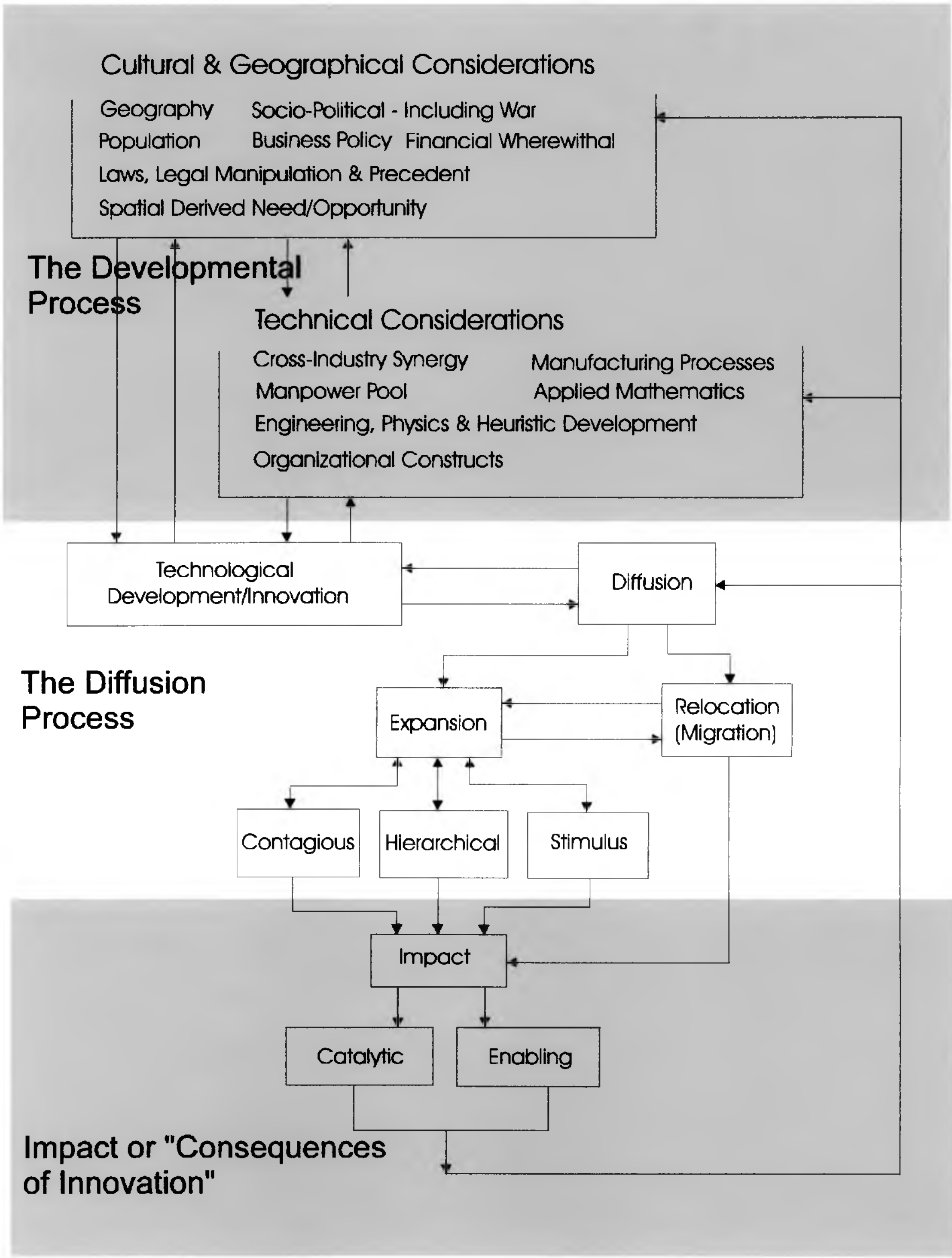


Figure 7. The development, diffusion, consequences feedback continuum.

technological innovation not yet conceived. That is, no one in 1750 anticipated, much less articulated, prerequisites required for manufacture of a steam traction engine by 1880.

Rogers (1995) discusses many categories of diffusion, from new technology, to health and hygiene practices, to family planning techniques. Specific to this thesis, development of the agricultural tractor began in the waning days of the Industrial Revolution. By the first decade of the 20^{th} century, diffusion was underway with a tractor utilizing the power plant still in use today – the internal combustion engine. Today the diffusion is complete. No farmer today engaging in commercial farming would seriously consider opting for draft animals as the motive power in the fields. However, many events and changing conditions transpired during this diffusion period. It is the purpose of this thesis to examine the relevance of Rogers' constructs for diffusion to determine if they apply to the agricultural tractor and if the diffusion pattern can be reconciled with the events of the day.

HISTORICAL AND TECHNOLOGICAL BACKGROUND

Technological development requires that a number of prerequisites be in place before development can actually occur (Murphy 1998). These prerequisites (Table 1) may be considered as cultural, geographical, and technical in nature. Once a critical mass of these prerequisites has accumulated, technological progress may proceed as a result of innovator initiative and/or market demand. In the case of the tractor, innovator initiative started with the notion that a steam engine was capable of satisfying the market demand for more motive power in the field to better utilize the dramatic advances in agricultural implements developed during the 19th century. Once carriage-mounted steam engines were pulled into the fields by teams of horses in support of thrashing, the transition to a steam traction engine and ultimately the gasoline traction engine was initiated.

Background and Approach

Prerequisites have been divided into two groups for purposes of examination. First are cultural and geographical considerations. This group, enumerated in Table 1, identifies those external factors related to the human aspects of any technological development (such as business policy, financial wherewithal, laws, legal manipulation, and precedents). This group might also be considered as the infrastructure prerequisites. As listed in Table 1 and Figure 7, the prerequisites are generic in nature. That is, the geographical considerations of tractor development are different from those of the cotton gin. The Rural Heartland was the site of the first market demand for the tractor. Companies entering this market clustered in what is identified as the *"tractor manufacturing belt"* in Figure 8. Numbers shown on the figure correspond to the location of the companies previously identified for inclusion in this study (Table 7). This location was not only near the initial market, but had ready access to the Great Lakes for delivery of raw materials, and had cross-industry synergy with the early automobile manufacturers. All six infrastructure prerequisites have relevance to the development of the agricultural tractor and are discussed as to their specific relevance in chapter 4 of this thesis. The second group addresses those factors required before development itself can

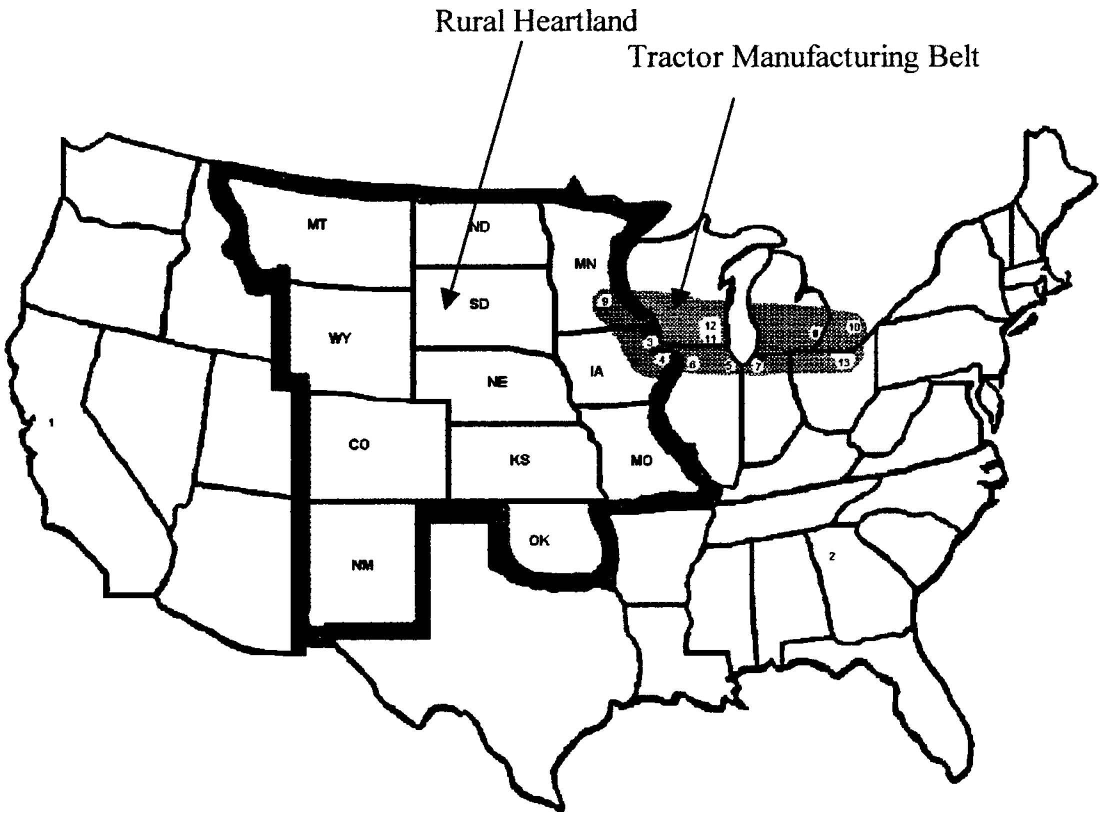


Figure 8. Rural Heartland and tractor manufacturing belt.

TABLE 7
TRACTOR MANUFACTURER LOCATION

	Company	City	State	Est
	White Motor Company			
	Deutz AG	Cologne	Germany	1864
1	Caterpillar	Stockton	CA	1904
2	AGCO	Duluth	GA	1990
3	Oliver	Charles City	IA	1929
4	John Deere	Grand Detour	IL	1843
5	International Harvester	Chicago	IL	1902
6	Minneapolis-Moline	Moline	IL	1929
7	Advance-Rumely	La Porte	IN	1853
8	Ford	Detroit	MI	1903
9	Emerson-Brantinghan	Minneapolis	MN	1904
10	Cockshutt	Brantford	ON (Can)	1877
	David Brown		U K	1860
11	Massey-Harris (Ferguson)	Racine	WI	1891
12	Allis-Chalmers	Milwaukee	WI	1847
13	J I Case	Racine	WI	1842

go forward, or which must be addressed in the course of development itself – regardless of cultural and geographical considerations (for example, cross industry synergy, organizational constructs, and manpower pool).

Implicit in this concept is that some number of these prerequisites must be present *in sufficient strength* for a critical mass of demand or (alternatively) developer expectation, to exist. At that time, technical development can and will go forward (Murphy 1998). Sobel (1996) makes this point convincingly in her book on John Harrison's development of the naval chronometer during the years 1730-1770.

The age of the agricultural tractor commenced in the waning years of the Industrial Revolution when the steam engine - the workhorse source of power fueling the Revolution - was equipped with a chassis, wheels and the requisite drive mechanisms to move steam power into the fields. The same prerequisites demanded for development of the agricultural tractor existed for other innovations of the Industrial Revolution as well. Nowhere was this truer than in the development of agricultural implements where such advancements as the iron plow (1819), a practical thrashing machine (1830), and the sulky plow (1859) were developed in advance of a steam traction engine (Hackett and Rukes 2001). Not all the prerequisites identified in Table 1 were put in place during the Industrial Revolution. Some were developed during the Baroque period immediately preceding the Industrial Revolution. Others were developed as an intrinsic part of tractor development itself. Determining the genesis of prerequisites requires some reverse engineering. This involves identifying the state of technology at the start of the Industrial Revolution and then determining what prerequisites were required to produce a given innovation, then tracing them to their origin. One of the developments of the Baroque period was the thermometer – part of a general advance in scientific instruments – and certainly representative of the engineering, physics, and heuristic development prerequisite. It is difficult to imagine the subsequent development and improvement of the steam engine without the presence of an adequate thermometer. One of the uses of a thermometer in a steam engine is to determine the temperature inside the boiler. Design of the boiler may, in the short term, be done heuristically, but long term must be refined with a knowledge of thermodynamics, and strength of materials – branches of applied mathematics made possible by the work of Isaac Newton during the Baroque period (Klemm 1964). Table 8 shows some of the considerations relative to each prerequisite which are directly related to tractor development and manufacture.

With the determination of the state of prerequisites described, the prerequisites, as identified in Table 8, are examined individually as to their particular relevance in the creation of a critical mass leading to the initiation of development of the agricultural tractor. This involves examining the physical components of the tractor (such as the source of motive power, the chassis, drive train, spring mounting, wheels, and instrumentation) and identifying the required prerequisites for that component to be built. All prerequisites need not be in place to the same level of sophistication. Some will evolve during the course of development itself. A steam engine mounted on a chassis but drawn into the field by horses need not have a drive train. Once the decision was made to make the device self propelled, a gearing mechanism and differential had to be developed. Once developed they become available for subsequent adoption on other innovations – most specifically the automobile.

TABLE 8
CONNOTATION OF PREREQUISITES RELATIVE
TO TRACTOR MANUFACTURE

Cultural & Geographical Considerations:	
Geography	Location of the initial market and that of manufacturing facilities
	Dust Bowl
Population	Adequate farm population with sufficient resources to justify purchase of a tractor.
Laws, Legal Manipulation & Precedent	Protection of intellectual property through patent law.
Spatially Derived Need/Opportunity	Breaking of the Great Plains and harvesting of Great Plains crops
Socio-Political – Including War	Economic booms and bust. WWI and WW II
Business Policy Financial Wherewithal	New Deal initiatives
Technological Considerations.	
Cross-Industry Synergy	Automotive technology applicable to tractor manufacture
Manpower Pool	Automotive and steel industries
Engineering, Physics & Heuristic Development	Thermodynamics, metallurgy
Organizational Constructs	Acquisitions, mergers, and conglomerates
Manufacturing Processes	Mass production – moving assembly line
Applied Mathematics	Engineering modeling techniques

(Murphy 1998)

Once the analysis has shown that a critical mass of prerequisites was in place, the emphasis of the thesis shifts to the tractor industry itself as the vehicle for tracing tractor development. Pioneers and pioneering companies are reviewed, and the maturation process from small companies, through acquisition and mergers into larger companies, departure from the market by companies, and the final stage of conglomerate ownership are examined. These evolutionary steps occurred as a result of the evolving technology, and the changing familial, societal, and exogenous forces of the era.

THE DIFFUSION PROCESS

Hypothesis

In the case of the tractor, diffusion was consistent with the expected pattern of diffusion of a technological innovation. Such diffusion may be successfully traced by determining the consequences of each characteristic of the innovation on each of the adopter categories. To this decision process must be added the current exogenous forces, as the economy and family/societal considerations, superimposed on each on each of the adopter categories during their adoption decision years. The consequences of the diffusion are reflected in its acting as an enabler for additional diffusion and as a catalyst for further development.

Background and Approach

Rogers (1995) characterizes innovators of diffusion as falling into one of five mutually exclusive categories (innovators, early adopters, early majority, late majority, and laggards). In assessing the role that exogenous forces played in the diffusion process, it is important to determine when the various adopter categories were making their adoption decision. This is accomplished by using Rogers' percentages for the various adopter categories and applying them to market penetration on a yearly basis. In this fashion, the specific external events impinging on each of the adopter categories is determined.

Rogers (1995) further identifies five characteristics of an innovation (relative advantage, compatibility, complexity, trialibility, and observability). In the case of the agricultural tractor, the elapsed period of time was about 75 years. This time lapse (more than two generations of farmers) must be coupled with domestic and world events (depression, boom, drought, war). Such a major diffusion process as the agricultural tractor, having major societal consequences, must be investigated temporally and spatially to determine its consistency with traditional diffusion theory. For instance, the major component of relative advantage of a technological innovation is its economic incentive. Ankli (1980) argued that in 1930, staying with a horse team was economically advantageous for the small farm, a disadvantage for the medium-sized farm, and advantageous again for the large farm. Ankli's conclusion resulted from the thesis that tractor operation was fixed-cost saving, but variable cost using, and that the more dominant of the two changed depending on farm size and draft animal requirements. Various other authors (Saloutos 1969; Clarke 1991) present differing economic models for various periods in the diffusion period and a cohesive determination of the economics will be used in determining the relative advantage association index. A second advantage is improvement in the quality of life. This characteristic was difficult to conceptualize and open to various evaluations over time. None of the above authors addresses the issue of quality of life involved in walking behind a plow all day vs. riding a tractor for the same period of time. Additionally, in the diffusion process of say, a Sony Walkman, an adopter may simply consign the equipment to a drawer if it proves individually unsatisfactory. Rogers (1995, 182) refers to this process as "*discontinuance*." Quoting, he says: "*Discontinuance is a decision to reject an innovation after having previously* *adopted it.*" In the case of the agricultural tractor, the decision to purchase was essentially one way – that is, discontinuance was simply not an option. Purchase frequently meant that the farmer was literally *"betting the farm"* on an ability to make its use a success. Once a farmer had committed to selection and purchase of a tractor, selling off the teams of animals, and converting the newly available feed acres to cash crops, it was virtually impossible to consider – much less achieve – a rejection of the tractor in favor of the old ways.

Using Rogers' categories and characteristics, a 5 x 5 association matrix consisting of adopter categories as rows and innovation characteristics as columns has been constructed. Numerical values are assigned indicating the value or consideration accorded of each characteristic in the adoption decision process for each category of adopter. Values for the association indices range from one to four with one indicating little or no influence in the decision, and four indicating a major factor for that category of adopter. While subjective in nature, the assignment of the association index is done on the basis of 25 unique scenarios – one for each intersection in the matrix. Each scenario is based on the subject innovator category and the years of adoption for that adopter category, the subject innovation characteristic, and the local, national and world events during the elapsed years involved. The pattern of the changing association index values in the matrix indicates the changing importance of the characteristics over time as diffusion progresses through the five categories of adopters. Creation of a sum column for the rows indicates the expanding knowledge base available through time. Creation of a sum row for the five characteristics indicates the relative importance of the five characteristics in the overall adoption process.

At least one reviewer of the association matrix concept has characterized it as a *"positivist exercise."* To the extent that association index values are assigned on a subjective basis, rooted in empirical sciences, this observation is correct. However, this simplistic observation ignores the purpose of, and resulting value, of the matrix. The absolute value of any given index value is subordinated to the process used by the researcher in arriving at its value. An assignment of 3 rather than 2 made for a particular row-column intersection is of little consequence if the subjective assignment of all index values was made on the same analytical basis, and with due respect for temporal considerations in the decision process and the exogenous forces at work. Under these considerations, the exercise itself as well as the resulting matrix prove its worth. Rigorous adherence to the methodology, as provided in this thesis, should provide insights into a particular diffusion process and point toward greater understanding of past, present and future diffusion processes.

To emphasize the points made above, it is important to recognize that a matrix is simply an array of elements, a_{ij}, where *i* and *j* correspond to the row/column location of an element in the matrix. In order to qualify a matrix for use as a model with the associated laws of matrix algebra, it must be populated with scalars. Hohn (1958) defines scalars as real and complex and the functions thereof. I define the elements in the association matrix as indices, thus differentiating them from scalars. Since the indices are not scalars, the matrix thus populated does not conform to the basic rules of matrix algebra, as particularly demonstrated by the *"commutative and associative laws of addition."* That is, in scalar algebra, $a + b = b + a$ (commutative law of addition), and $a + (b + c) = (a + b) + c$ (associative law of addition). In this fashion, the association matrix is not considered a model, nor is it subject to, or amenable to, any of the laws of matrix algebra as exemplified above. The association matrix rests on its own as a product of subjective analysis, and carries with it the inherent potential for further empirical study.

DATA

The study area for this thesis is (though not exclusively) the area defined by the Federal Reserve Bank of Kansas City as the Rural Heartland. The Rural Heartland was chosen because much of the early diffusion of the tractor (and especially the earlier steam traction engine) occurred here. Other areas of the country are included in the thesis when they play a significant role in the diffusion process. The Plantation South, for example, was late in adopting the tractor with draft animals, and particularly mules, continuing in significant use until after World War II.

The time frame included in the analysis of development of the tractor industry extends from its inception until the present. This period covers all the eras encountered in the industry from its infancy until its mature state of the present day. The time frame to be examined for diffusion is from roughly 1880 until 1954. During this period, the steam traction engine experienced its period of usefulness and was superceded by the gasoline traction engine – subsequently termed the tractor. By 1954 the agricultural tractor had displaced draft animals as the primary source of power on the farms of the United States (USDA 2001). While the time periods vary from development to diffusion, it is deemed important to cover the respective periods to accurately analyze the considerations being addressed.

A key indicator of adoption of the tractor is market penetration achieved at any point in time by the tractor. Ideally, the number of farms with tractors vs. the total number of farms on a state-by-state basis for the years involved would form the basis for the study. This information is not available for all years, for all states for all of the diffusion period. If it could be accumulated, it would be from a significant number of sources with attendant problems of consistency. However, Letourneau (1993) provides information concerning overall tractor *production* figures from 1907 through to 1950. For purposes of this thesis these production figures are used as surrogates to approximate market penetration. The numbers presented have the dual advantages of being consistently presented from a single source and have yearly production figures as opposed to the more commonly quoted five year figures (generally from the U.S. Agricultural Census). Cavert (1956) uses USDA Agricultural Research data indicating significantly fewer actual tractors on farms than simple cumulative production would indicate. However, the resulting S-curve is consistent with that of the Letourneau numbers. Clarke (1991) uses yet a third set of numbers purported to represent the number of tractors purchased in the U.S. from 1910 through 1939. Again, these numbers are lower than the production figures, but duplicate the trends of both Letourneau and Cavert.

ORGANIZATION

The organization of the thesis is structured after Figure 7. The development of the tractor is discussed first on the basis of the prerequisites and the historical realization of those prerequisites. The development of the tractor is traced through examination of a set of representative tractor manufacturers representing the tractor industry. The firms selected allow an examination of the industry as it matured from pioneers and pioneering firms specializing in farm implements, to small firms specializing in tractors, to larger firms made big by growth, acquisitions and mergers, to conglomerates.

The diffusion process is examined in two sections. First is an examination of certain diffusion phenomena. This examination includes a review of the standard normal distribution curve of adoption and the S-curve (logistic) curve of cumulative adoption representing market penetration. This is followed by discussion of Rogers' (1995) five categories of adopters with emphasis on adoption of a technological innovation, and his five characteristics of an innovation with emphasis on the tractor in particular. The development of the association matrix is then presented. Once completed, the changing pattern of association indices within the matrix is discussed as to their implications regarding changing importance of characteristics on successive categories of adopters. The row and column totals are examined for their implications regarding knowledge accumulation by successive categories of adopters and the relative importance of each category. All this discussion is couched in terms of the diffusion of the agricultural tractor. The consequences of diffusion are discussed as an integral part of the diffusion process and their implications in activating the feedback loops indicated in Figure 7.

Conclusions are reached as to the acceptance of the hypothesis. Further conclusions are presented as to the applicability of this study (particularly the assignment of dates to adopter categories and the creation of the association matrix) in examining other instances of diffusion of a technological innovation. Its potential applicability in the diffusion of other problems of innovation as religion/ideology, health/epidemic, and style/fad is also discussed.

ANALYSIS

Data sources generally may be divided into those chronicling historical events and synthesizing conclusions (Baker 1928; King 1929; MacLeod 1992; Prunty 1955; Rasmussen 1962), and those that present an hypothesis and analyze on the basis of a model (Clarke 1991; Day 1967; Jones 1960, 1963, 1967; Kauffman 1993; Lew 2000; Morrill 1968; Musoke 1981).

Development and diffusion of the steam traction engine are examined as the final precursor, embodying the final prerequisites, for the gasoline traction engine or tractor. This is accomplished by identifying the major technological components of the steam traction engine (chassis, steam engine, drive train, wheels, steering) and the prerequisites required for their implementation. Development analysis commences roughly with the steam traction engine in 1880 and segues into the gasoline traction engine at approximately 1900 as internal combustion engines began to be tried in place of a steam engine but mounted on a steam traction engine chassis. At this point, development is traced through identification of the characteristics and contributions of companies participating in tractor manufacture, and the evolution of their product in response to market demand and technological advancement. Over 400 companies have had products on the market with only the strongest having survived. The others have gone out of business, withdrawn from the industry, been acquired, or merged. The companies selected represent a cross-section of the tractor industry regarding corporate histories and contributions. This examination is supplemented with two appendices showing the genealogy of the subject companies and the characteristics of models produced indicating the evolution of tractor functionality and the target market of the firms. The first appendix contains a schematic for the genealogy of the target firms. Name, place and date of founding, names, places and dates of major acquisitions and mergers, corporate name changes are shown, and significant product development dates are included. The second appendix consists of tables for each of the manufacturers organized with individual model offerings as rows, and significant characteristics of that tractor model (dates of production, units produced, date(s) of Nebraska testing laboratory submission, fuel, weight, etc) as columns. Examining these tables provides the basis for conclusions as to the evolution of tractor functionality (ratio of belt to drawbar horsepower, introduction of pneumatic tires, PTOs, etc.) and the target market of the firms based on the power, weight, units produced, etc. of the models marketed.

The diffusion process is examined by starting with an examination of some diffusion phenomena followed by application of these phenomena to the agricultural tractor. Rogers' (1995) five categories of adopters (innovators, early adopters, early majority, late majority, and laggards) are examined with emphasis on adoption of a technological innovation, but not the tractor specifically. Each category of adopter is defined as they are used subsequently in the thesis. Similarly, Rogers' five attributes of an innovation (relative advantage, compatibility, complexity, trialibility, and operability) are defined as they are used in the thesis with emphasis on the tractor as the target technological innovation. This process is examined for its specific application to the agricultural tractor.

Two curves form a portion of the classical discussion of diffusion of innovation and are routinely referenced throughout the literature. These are the normal distribution curve showing the rate of adoption over time, and the S-curve (logistic) showing the cumulative adoption of an innovation over time (Chapin 1928; Rogers 1958, 1995; Gould 1969). These curves for a technological innovation are superimposed on each other as the basis for further analysis. Four more curves are superimposed for such analysis. These include an S-curve (logistic) for potential adopters, potential for excess profits, and theoretical risk, and yet another curve representing actual risk. The S-curve for potential adopters simply acknowledges that 100 percent of the potential pool of adopters is divided at any time between actual and potential adopters. Thus the curve of potential adopters is a mirror image of the cumulative adoption curve. The curve of potential excess profits corresponds exactly to the curve of potential adopters. This curve is predicated on the theory that since a farmer operates in a perfect competition economy, the potential for profits in excess of other members the economic community decreases as the number of adopters goes up. Similarly, the curve of theoretical risk also corresponds to the curve of potential adopters since risk of adoption decreases the more people have made the adoption decision and have created synergy in the innovation's use. Finally, the curve of actual risk acknowledges that actual risk may be greater or less than theoretical risk depending on the ultimate success of the innovation. For a successful innovation as the agricultural tractor, the actual risk would have been considerably lower than theoretical risk at every point in the diffusion process. Addition of these curves to the traditional curves of diffusion theory provides a more complete picture of the interaction of forces at work during the innovation period.

Following these theoretical constructs, this thesis examines the diffusion of the agricultural tractor first on the determination of the years during which the various adopter categories were actually making their adoption decisions. This is accomplished by using the yearly tractor production to determine the cumulative production on a yearly basis. For purposes of this paper, cumulative tractor production is used as a surrogate for market penetration through to the mid-fifties. Using Rogers' (1995) percentages for defining adopter categories, the years in which the first three categories were making their decision to adopt are identified. Superimposing the events of the day onto the years of adoption allows examination of the decision process by each of the adopter categories. The presumption here is that the individual adopters based their decisions on the characteristics of the innovation and the then-current real world conditions confronting the adopter. Secondly, based on the result of this examination, an association index has been assigned for each combination of adopter category and characteristic of the innovation. The association index is based on a subjective analysis of the category being considered, the characteristic of the innovation and the external events taking place based on the adoption years determined for each of the adopter categories. This information is presented in matrix form and conclusions are drawn from the character of the matrix. The matrix provides a numerically based presentation of the findings. However, since the matrix has been populated with association indices obtained subjectively, the matrix is not considered as a basis for further mathematical analysis. Figure 9 shows the schema used in creation of the association matrix.

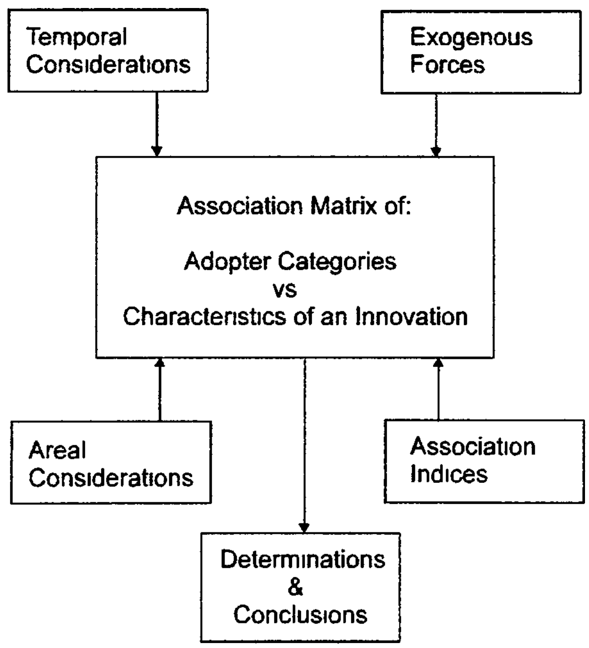


Figure 9. Schema for association matrix.

INTERPRETATION OF RESULTS

The development phase is judged on the basis of the list of prerequisites. If true, all prerequisites as enumerated in Table 1 and Figure 7 are relevant to the start of tractor development. The applicability of the various prerequisites is verified on the basis of reverse engineering from characteristics of innovations in existence at the time of tractor development, as well as the introduction of new technology as an integral part of tractor development. With the prerequisites in place (i.e. the wherewithal for initiation of development) some combination of developer initiative and/or market demand should trigger development. The association matrix, developed according to Figure 9, is then referenced to determine the validity of the feedback loops and their influence on the development of the tractor in terms of product evolution and functionality.

Hypothesis

The hypothesis will be shown as valid if the rises and falls in production can be related to real world events and conditions as they inhibited or encouraged diffusion. First, production (and hence market penetration) did fluctuate during the diffusion period. Second, major local, national and world events took place which could have had the effect of encouraging or discouraging adoption. The diffusion analysis identifying the years of adoption by the various adoption categories and superimposing the external events are then used in construction of the association matrix. Construction of the association matrix allows validation of the concept that the farmers making the adoption decision were doing so on the basis of rational analysis of their individual situation during the years of adoption and considering the exogenous events of the period. The validity of the feedback loops is tested by tracing the needs and desires of the farmers. If the hypothesis is correct, the consequences should feedback to the start of the diffusion process for different audiences of adopters and to the development phase as new features were incorporated into the newer model tractors. The results and advantages of tractor adoption should act as an enabling (i.e. work as a motor for change) element in development of tractor enhancements and/or more and more varied use through additional diffusion. Alternatively, the results and advantages of tractor adoption should act as a catalyst (i.e. encouraging rapid change) for further development in the same manner that the steam traction engine acted as a catalyst for development of the gasoline traction engine or tractor.

Further Application

The methodology presented in this thesis appears to offer a new tool in the structured examination of diffusion of a technological innovation, both in historical as well as contemporary diffusion settings. For an ongoing diffusion process, the technique should allow researchers to determine the category of adopter making an adoption decision based on the state of market penetration. That is, for early majority adopters, what were the events of the day and their impact on consideration of compatibility, complexity, and the other characteristics of adoption? From this, the characteristics of importance to the current category of adopters may be stressed in order to maximize the rate of adoption.

In addition to technological innovation, categories as religion/ideology, health/ epidemic, and style /fad should prove amenable to a similar approach.

CHAPTER 4

PREREQUISITES AND DEVELOPMENT OF THE AGRICULTURAL TRACTOR

INTRODUCTION

It is the contention here that technological diffusion can go forward only after prerequisites for technological development are in place and that the innovation has reached such a state of development that the initial target market (the innovators) are induced to make the adoption decision. In this chapter a set of prerequisites are discussed relative to their progress and state of achievement leading into the tractor manufacturing era. These prerequisites (Table 1; Figure 7) may be divided into cultural and geographical considerations followed by technical considerations.

Following the discussion of prerequisites, the development and maturation of the tractor manufacturing industry are discussed in the context of twelve manufacturing companies deemed to be representative of the tractor industry in general which, over the years, has seen some 400 participants for some period of time.

CULTURAL AND GEOGRAPHICAL PREREQUISITES

Cultural and geographical considerations are vital prerequisites for technological development. They, in effect, provide the social framework; the laws, financial wherewithal, and manpower, necessary for an atmosphere within a society in which technological development may be conceived and executed.

Geography

Much can be made over the geographical fortunes of certain nations relative to advances of technology. For the purposes of this thesis it is simply noted that access to raw materials is one of the paramount requirements for converting technology into commerce.

Britain, in the mid 18th century had access to cotton from its colonial holdings in the Americas and India as a raw material for its burgeoning textile industry. Just as important is the fact that a seam of coal runs from Britain through Belgium, Northern France and the Ruhr Valley in Germany. Since the revolutionizing technology primarily involved a conversion of energy utilization from human/draft animals plus wind and water power to fossil fuel use, it is not surprising that much of the early industrialization took place along this seam. Using coal as the energy source, the smelting of iron ore and powering of the steam engine was possible. By the sheer luck of the draw, Britain not only had significant coal reserves but also iron ore in near proximity to the coal. Since timber supplies were also running low in Britain, a motivation was provided for exploiting their alternative fuel resource. Finally, Britain was blessed with coastal waterways and navigable rivers facilitating the transport of the heavy ores. Prior to the railroads, movement by land was difficult and expensive, particularly as loads became heavier (Murphy 1998).

By contrast, the United States had an almost limitless supply of forests at the time. This coupled with abundant rivers capable of supplying water power delayed the need to exploit the coal available in Pennsylvania and Ohio until the quality of coal smelted iron plus the demand for iron dictated a move from charcoal to coke for smelting.

The geography of the U.S. demanded creation of a means to place power and then motive power in the fields in the hands of farmers. The tasks of breaking up the prairies and threshing the grain crops required such power to fully utilize the advances in agricultural implements accomplished during the first half of the 19th century, and steam and then the internal combustion engine provided the vehicle for meeting this demand (Cochran 1983).

Population

During the early part of the 18th century Britain and Western Europe started experiencing a dramatic surge in population. Factors favoring this increase included agriculture, plague and war (Stearns 1993).

Potatoes were introduced from the New World into Ireland, France and Prussia in the waning years of the 17th century. After a period of skepticism, the potato was embraced as a staple food because it provided a high caloric value, and it could be grown in smaller and frequently less fertile plots of ground. For some time it was not subject to the periodic diseases or blights of the grains which had been the staple of European peasant diets. At about the same time the Dutch were discovering that nitrogen-fixing crops could be used to keep croplands fertile without resorting to lands laying fallow every third year. The Dutch were also developing technology for draining swampland for use in agriculture. This technology was quickly imported to Eastern Britain where marshes were converted to cultivation.

By this time Europe had recovered from the lingering effects of the plague of the 14th century which had extended into the 16th century and there were no new plagues during this period.

Europe experienced a period of relative calm and an absence of the most devastating forms of war during the period between 1715 and 1792. Of course the American Revolution occurred during this period, but on the grand scale of European war it was nominal in size and of relatively little importance on the continent.

High caloric potatoes, nitrogen-fixing crops, and claimed marshes and swamps provided more nutrition, and more and more productive croplands providing the impetus for dramatic population increases. Lack of plague and war allowed more people to survive into their productive years. As a result, Britain's population doubled from 1750 to 1800 while France's population increased by 50%. Increased population and a more abundant food supply pushed people to seek alternative life styles away from the subsistence farm. It also provided a ready market for inexpensive manufactured goods whereas the subsistence farmer had provided for virtually all his or her own consumable goods (Stearns 1993). Toynbee addresses these issues in his Lectures II and III in which he discusses population and agriculture in England in 1760 (Toynbee 1884).

The excess of labor thus produced and its placement in the new cities produced both a burden and an opportunity to cope with and provide for these people. Their very presence demanded change in the social structure and technological advancement fueled the changes.

In the second half of the 19th century the population of the U.S. was expanding rapidly. It was also shifting westward. There were farmers to work the land and harvest the fruits of their labor. There were also consumers in the cities to buy their product. The railroad network was essentially in place, providing a means of transporting harvests from the Rural Heartland to the markets of the east.

Socio-Political Considerations – Including War

Socio-political consideration is intended to encompass those issues of the era generally handled by authors as the Industrial Revolution. It is not within the scope of this thesis to delve into this aspect of prerequisites for technological change other than superficially.

The early Industrial Revolution in Britain was dependent on an almost endless supply of cheap labor, driven mercilessly hard by shop foremen and the system in general. As the yeoman of the countryside were forced into the industrial centers they were confronted with a reduced standard of living plus a total upheaval in the mechanics of family life (Stearns 1993). The family unit, traditionally centered on the home and whatever acres of land they possessed with children and adults performing in well established contributory ways, was gone. The seasonal aspect of country life with periods of hard work followed by leisurely periods was replaced with a regimented requirement to appear at the factory regularly, on time, and to produce at a designated pace during one's shift. Regional festival days such as those celebrated when the crop was safely in were done away with. The machines of the early revolution, most especially in the textile industry, called for many nimble hands and little training or skill. Young women and children filled this bill nicely and the bodies and minds attached to the hands were expendable – another set of hands was available if one set faltered or became damaged (Murphy 1998).

Other transitional problems abounded. There was neither a regular provision for illness or injury nor a social safety net for the infirm or elderly. Where an older couple had previously depended on a small plot of land for a modest amount of food there was now no such option.

Frequent economic slumps often caused unemployment rates to soar, even for the skilled craftsman. Thus the capital investment required for the new factories was, to a significant degree, subsidized, however unwillingly, by the ever increasing number of potential workers for whom there was no longer a place in agriculture (Stearns 1993). It is not surprising that periodic rebellions such as those of the Luddites would erupt.

Without expanding extensively into the political area, the changing times, the potential for economic gain, the rising industrialist class elbowing itself into the moneyed, if not cultured, strata of British society all provided for a political climate where laws and legal manipulations bolstered by precedent were easily accommodated.

Britain was, for the most part, spared and isolated from the regional conflicts experienced on the continent. The United States, following their emergence as a nation, was also spared the human and economic capital required of war. So, war or its absence played a role in allowing the embrace and extension of technology to go forward in Britain and the United States with less diversion of resources than on the European continent. The geography of these two nations again played its part in fostering the climate of technological advance.

The above should not be taken to mean that the U.S. has not been engaged in war. However, following the war of 1812, there have been no foreign invasions or attempts at such. Following the Civil War the U.S. has experienced no combat on its mainland. The wars since the advent of the agricultural tractor have, in fact, acted as a boost to the agricultural economy. World War I brought a demand for U.S. built tractors particularly in Briton. While few tractors were manufactured during World War II, demand for their services continued to grow with a subsequent robust demand for tractor production after 1945.

Financial Wherewithal

Western Europe in 1700 consisted of nation states each supporting an advanced agricultural society. There was a large commercial sector and a great deal of manually produced manufacturing. Little capital was available for support of the technology development required for the initiation of the Industrial Revolution. The surge in population and the resulting expanded internal and external trade started the process of society's throwing off enough capital to support technological initiative. Britain was particularly well suited with its colonies in the Americas and India. These colonies provided capital, markets and raw materials for the burgeoning manufacturing processes. As business opportunity fed the desire for better technology to improve profits, so did the surging population and enlarged pool of craftsmen, mechanics, metal workers and artisans supply the initiative for change. Once started, with ever increasing population and markets, society continued to throw off ever more cash to support technology (Stearns 1993).

In the United States, the process developed more slowly than in Britain. Until the revolution in 1776, the American colonies were largely maintained for the benefit of the British industrial machine. Afterwards, the process commenced in the waning years of the 18th century that had commenced at the start of the century in Britain. By 1820 to 1840 the United States had achieved its own momentum. Cash, however, was scarcer in the United States as a more significant portion of all financing was devoted to building infrastructure and buildings in particular. This created a demand for manufactured goods across the board, from agriculture to the building trades. There was some offset in investment costs because of the abundance of readily available, inexpensive wood throughout the United States. This supply provided building materials and inexpensive fuel relative to Britain where wood had become scarce and coal more expensive than wood for fuel (Cochran 1993). Entrepreneurs fostered friendly banking laws and share companies appeared earlier in the cycle than in Britain. In the United States, as in Europe, the population was surging. Where the population of the Americas was 1/8th that of Europe in 1700, it had grown to better than 1/4th by 1850 (World Population 1999).

Since the advent of the agricultural tractor, demand has risen during times of plenty and declined during depressions. The agricultural depression of the 1920s followed by the Great Depression caused significant but temporary dampening of demand for tractors. During the Great Depression, of course, the federal government intervened to some extent with government programs designed to entice farmers to buy rather than delay.

Business Policy

Financial wherewithal was available within the society to sponsor the technological changes becoming possible as discussed previously. Businesses, however, were forced to change in order to take advantage of the technology available to them. As the factory system emerged, capital formation became a paramount issue. Capital requirements stemmed from the additional costs of real estate, factory buildings and equipment demanded by a factory no longer operating out of a craftsman's home or workshop. Re-equipping to take advantage of improved manufacturing equipment demanded a constant infusion of capital to be repaid out of future earnings. Many firms were established as partnerships because the necessary capital was not available otherwise. Active (those actually participating in the operation of the company) vs. passive (those merely providing capital) partners became common with the passive partner providing a significant part of required capital. Share companies began to appear. Family firms were forced to branch out and to hire outsiders to participate in the more specialized organizational constructs required of firms employing non-family members in specialized labor functions. In some instances holders of raw materials allied themselves with manufacturers to begin the concept of the vertically integrated company. All of these activities had to be coordinated and were, in fact, orchestrated in lockstep with the making of law, legal manipulation and precedent discussed subsequently (Murphy 1998).

The climate for all such activities varied from country to country with Britain and the fledgling United States facing a lesser number of problems than their continental counterparts. Business policy and its ability to adapt had nothing to do with the available technology. It had everything to do with the existing establishment – at both ends of the spectrum from entrepreneur to peasant – and its desire and perceived need to avoid change. In Britain and the United States business policy expanded and shaped itself to meet the challenges of change. Other countries, such as France and Germany, were burdened with unfavorable circumstances such as the guild system in Germany and the peasantry in France. Both acted as a deterrent to business policy adaptation.

Of a completely different nature were the differences in business practice allowed by such inventions as the telegraph. Samuel F. B. Morse had, in 1837, made use of the telegraph a commercially viable option through his perfection of transmission and reception in code. Suddenly, business operations, such as the transfer of orders for goods, could be accomplished in minutes rather than days or weeks. While slow to catch on, by 1850 much business was being conducted by telegraph, and several railroads were controlling their far flung operations via telegraph (Cochran 1983). .

The changes in business policy are reflected in the changing structure of the tractor industry as it matured. First there were the blacksmiths, then came the independent manufacturers. As the demands for capital grew, manufacturers turned to corporations, mergers, and acquisitions. Finally, came the domestic and global conglomerates.

Spatially Derived Need/Opportunity

Need (as perceived by society) and opportunity are the precipitating requisites tying geography to technological development. During the years of the Industrial Revolution few examples, not even the advances in textile manufacturing and equipment demonstrate this issue so forcefully as the development of the steam engine and its application both as a stationary power source, its adaptation to transportation and ultimately to agriculture (both stationary and motive). Britain is specifically noted for its lead in this decisive area of technological development and industrialization. Britain had the need, driven by a burgeoning economy requiring alternative fuel sources plus the demand for enhanced transportation beyond the navigable coastal waters, rivers, canals and roads available at the quarter point of the 19th century. The United States had abundant wood as a fuel supply as well as strategically located waterpower. Hence its motivation for embracing the steam engine came initially as a result of its transportation needs. Only later were the needs of agriculture addressed by use of steam power.

Laws, Legal Manipulation, and Precedent

As the Industrial Revolution began to take hold and pick up momentum, bankers, landholders, manufacturers, artisans, and virtually any definable group imaginable pressed for and achieved laws favorable to their cause (with the possible exception of the yeoman-turned-factor worker.)

In addition to the extremely rapid population growth during the 18th century and enhanced agricultural productivity, the larger British landholders pried land from many farmers with small holdings through the legal precedent of the Enclosure Act. Farmers were required under the Act to enclose their landholdings, generally with hedgerows. The expense and lost land was beyond many small landholders, forcing them to sell to owners of the larger estates. Thus the British landscape became dominated by the large estates. While the estates retained some of the smaller landholders as laborers, they did not require all the displaced farmers. Additionally, the estates were more efficient and productive, throwing even more yeomen off the land while still providing food for the growing cities (Stearns 1993). Toynbee also discussed this issue in his lecture V – England in 1760 – the Decay of the Yeomanry (Toynbee 1884). While this bit of chicanery rightfully falls under the category of a legalized land grab, it did have the secondary result of creating a more favorable climate for the revolution to come – industrialization.

Protective tariffs were passed in Britain, and almost immediately upon the Declaration of Independence, in the United States. Early in the history of the new country a debate existed regarding the appropriate path of the new nation. Thomas Jefferson, among others, believed that the new democracy could only be maintained by a nation of private, independent farmers. This would have continued the pattern established during the colonial period of exporting raw materials to Europe, chiefly agricultural products as tobacco, indigo and cotton, in exchange for manufactured goods. The second school, as exemplified by Alexander Hamilton, believed the U.S. must become a manufacturing nation in order to promote the general wealth and to insure further financial independence from Britain. The latter school won out and by 1790

Hamilton had submitted papers to the government urging the adoption of protective tariffs for the nation's emerging industries (Stearns 1993).

From the standpoint of technology itself, however, the issue of the protection of intellectual property was most urgent. The Constitution of 1787 provided in broad terms for the patenting and copyrighting of inventions and literature to encourage development of intellectual property. Congress pursued this vital bit of the nation's business and subsequently passed the Patent Act of 1790. This act was flawed in many respects and was therefore superceded by a new law, passed in 1793. While still flawed, this new act survived until 1836 when a third version was passed. This law restored confidence in patent rights not available in the previous versions which had led to numerous court battles. Proof that the Industrial Revolution and the driving force of technology innovation had spread to the United States and picked up momentum throughout the 19th century can be seen in Figure 10. This figure showing patents issued by decade from the 1790s through the 1850s and for the single year of 1860 (Himdle and Lubar 1988).

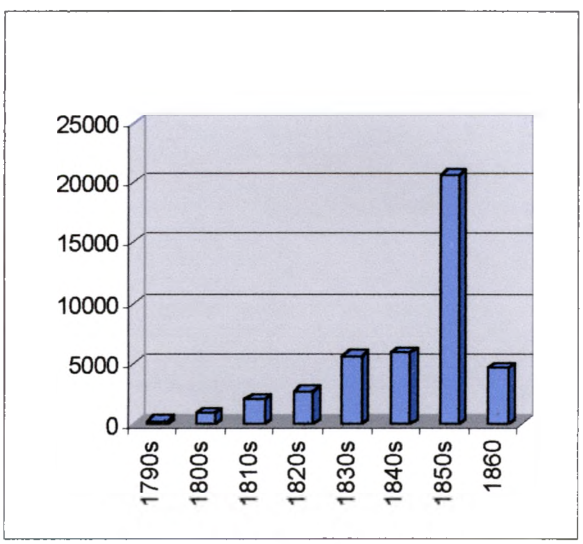


Figure 10 – U.S. Patents issued, 1790-1860.

The year 1860, the last year prior to the interruption (some might say eruption) caused by the Civil War showed almost twice as many patent grants issued than had been issued in 1856, and the number of patents granted had gone up monotonically for the previous 13 years. The U.S. was an agricultural society during this period, and therefore a significant portion of these patents was agricultural in nature (USDA 2001).

TECHNOLOGICAL PREREQUISITES

Geographical and cultural prerequisites establish a society, financial wherewithal, laws, and generally an atmosphere whereby it is possible for technological development to progress. Similarly, certain engineering, scientific and mathematical skills must also have been developed and be available to a sufficient degree, and to a sufficient number of people so as to establish a developmental synergism for technological development.

Cross-Industry Synergy

The concept of cross-industry synergy is best illustrated by the triangle of locomotive manufacture, a broadly competent machine tool industry and the textile industry. As the Industrial Revolution was driven by the textile industry, mills brought in mechanics who built their mostly wooden machinery by hand on site. A few large mills also sold machinery and a very few specialized shops existed selling all types of spinning and weaving equipment from standard patterns. An immediate effect of the spread of railroads was the demand for rolling stock. This created a demand for specialized machine tool factories capable of manufacturing engine parts, boilers, frames, axles and wheels plus a demand for the tools for production itself: lathes, drills, milling machines filing jigs, gear cutters and the like. The United States kept pace with Britain in development and manufacture of machine tools, and by 1828 some experts found American machine tools superior to those manufactured in Britain. As the industry of manufacturing locomotives expanded, the development and manufacture of machine tools kept apace. The ability to manufacture precision parts on an assembly line basis then fed back to the textile industry where weaving and spinning equipment came to be manufactured exclusively by third party manufacturers. Add to this example the manufacture of farm implements, household goods including stoves, building of steel hulled, steam driven ships, arms manufacture, construction trade tools and equipment, and ultimately boilers, steam traction engines, and the cross-industry synergy thus accomplished becomes obvious and becomes one of the prerequisites for technological development on a broad front (Stearns 1993; Murphy 1998).

Just as the building of steel hulled ships, steam powered locomotives and boiler construction in general provided for cross industry for the steam traction engine, so to did similar relationships assist the gasoline traction engine. Manufacture of automobiles provided tremendous synergy as did the burgeoning airplane industry. Henry Ford's manufacture of over 15 million Model-Ts by 1927 attest to the synergy potentially available. The tractor manufacture belt corresponded to that of auto manufacture for the obvious logistical reasons in insuring availability of raw materials. However, the availability of trained engineers and craftsmen from the automotive area provided a manpower pool of cross-industry synergy as well.

Applied Mathematics

> *Mathematics is the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions and of space configurations and their structure, measurement, transformations, and generalizations.* (*Webster's New Collegiate Dictionary*, 7th ed., s.v. "mathematics")

Traditionally, mathematics has been somewhat arbitrarily divided into pure and applied strains. Pure mathematicians examine the subject and individual problems based on its theoretical, intellectual interest. Applied mathematicians develop tools and techniques for solving specific problems in business, engineering and science. Happily the problem with these traditional definitions is that with the advent of electronic digital computation, many pure mathematical problem solutions are now being used in the solution of applied problems.

As the serge in technology began, however, it is safe to say that most such mathematical progress remained isolated in the intellectual world as opposed to day-to-day technology. Such applied fields as optics and astronomy were the exceptions. In general, the marriage of mathematics and science with industry occurred only after the 1830's when the industrial revolution was well under way and the state of technology had reached a stage where heuristic development could no longer provide the solutions to problems being encountered.

Perhaps the most prolific mathematician of the 18th century was Leonhard Euler of Switzerland. He produced hundreds of research papers and books on the subjects of differential and integral infinite calculus, algebra, geometry, mechanics and the calculus of variations. In France, Joseph-Louis Lagrange contributed to mechanics, foundations of the calculus, calculus of variations, probability theory, and theories of numbers and equations – including the famous Lagrangean polynomial. The French astronomer Pierre-Simon Laplace succeeded in applying probability theory and analysis to the Newtonian theory of celestial mechanics. One of his developments in this effort was the Laplace transform. In this construct partial differential equations which were otherwise intractable with analytical methods could be solved by converting them into algebraic problems through an integral transform. After solving the algebraic expression thus created, the process could be reversed through an inverse transform process to reset the solution in the original problem space (O'Conner and Robertson 1999, Churchill 1944).

The automotive and aircraft industries provided advancements in engineering mathematics equally adaptable to the tractor industry. Problems in modeling engineering mechanics and thermodynamics transfer from one industry to another with ease. Trained engineers and mathematicians capable of defining and solving sets of simultaneous partial differential equations for heat transfer care little if the object of interest is an automobile, an aircraft, or a power generating plant.

Engineering, Physics, and Heuristic Development

Engineering and physical principles involve the application of all available tools to the solution of technical problems. Such solutions generally start with the heuristic process. Heuristic development stems from the Greek word *heuriskein,* meaning to find out or discover. (*Compton's Interactive Encyclopedia*, 1999, s.v. "heuristic") Webster defines heuristic as *"to guide, discover, or reveal - valuable for empirical research, but* *unproved, or incapable of proof."* (*Webster's New Collegiate Dictionary*, 7^{th} ed., s.v. "heuristic"). In engineering practice, this approach is applied to trial and error efforts to solve a problem. In simple problems this usually takes the form of *"if it breaks make it bigger and stronger next time"* and *"if it doesn't work this way try something else."* As the science of engineering progressed, initial solutions were frequently sought heuristically, then a rigorous, scientific description of the problem was developed mathematically.

In the early days of the evolution to machinery, such machines could readily be understood by master mechanics by observation, disassembly and re-assembly of the machine. After the 1830's, more and more problems were encountered where the scientific approach provided solutions to elusive problems where economics and/or safety became paramount. As machines became more complex and expensive, such issues as heat conductivity of materials, thermodynamics, chemistry, strength of materials, statics and dynamics, forced manufacturers into a more scientific approach to making their products less expensive to manufacture, more reliable, safer, and more consistent. The development of mathematics through the millennia, for the most part done as an intellectual exercise, provided an important tool in the toolbox for the scientific approach to technological development (Stearns 1993; Murphy 1998). Perhaps the most striking example of interest here is that of heuristic development segueing into more scientific analysis of the boiler. Boilers were dangerous to be around. Metals subjected to high temperatures and pressures are subject to failure. When a failed piece of equipment emits superheated steam, it is dangerous to be in the area. As the steam era progressed, so to did the knowledge of thermodynamics and metallurgy and their application to the manufacture of boilers to make them stronger, lighter and safer.

Manpower Pool

In the middle of the 18th century the guild system still existed strongly in Europe. In Britain the guild system, never as strong as on the continent, had been eliminated. In the United States there had never been a guild system. Where apprentice programs had once been in effect in the U.S., by 1810 they were no longer mandatory.

The guilds sought to protect members from change in working conditions through limiting new technology and by preventing an employer from creating a significant wage imbalance or threatening of wage rates by hiring too many workers. Guilds worked well in a stable economy, but their fundamental purpose for being was at cross purposes with technological advancement, innovation and application (Stearns 1993).

Improved production in Britain at this time was achieved by the minute division of labor. The extent of this division was not possible in the United States due to the mobility of the work force combined with the smaller market for any given product. With the onset of rapid mechanization, the smaller size of U.S. factories became an advantage as there were less sunk costs in equipment than in Britain. This coupled with the attitude of American workers and entrepreneurs allowed for easier obsolescence of equipment and techniques than in Britain. However, Cochran quotes Paul Mathias as stating that the *"trigger mechanisms"* leading to rapid industrialism in Britain arose from demands, high wages and scarce labor pool (Cochran 1983, 52). These were, of course, the identical factors in a different setting that existed in the rapidly developing United States.

Regardless of locale, early technology depended on the availability of skilled artisan-entrepreneurs striving for improvements in current technology. Their thinking was more visual than theoretical in application. Workbench skills were more important than scientific knowledge at this time. In the United States a larger portion of the workforce demonstrated this practical, all-purpose machine builder capability than in Britain. There the extreme division of labor had produced a labor force, though greater in number than in the U.S., that had a limited range of individual skills (Cochran 1983).

As the United States progressed from the individual craftsman to the small shop to the factory, and from one-off manufacture to the moving assembly line, the role of an individual craftsman became more similar to the British counterpart of the previous century. This specialization came slowly to automobile and tractor manufacture and even more slowly for airplanes. However, as the product became more complex and required more skills and labor hours for manufacture, specialization was inevitable.

Organizational Constructs

In this context organizational construct refers to the gamut of problems and challenges encountered as factory size changed in human, capital and organizational ways. Prior to the late 18th century, manufacturing processes centered on individual households with collaboration and division of skills and responsibility amongst perhaps ten people. Though in the early industrialization process, the size of factories was still small, they brought more people into larger groups in working relationships. This in turn required development of personnel assignments as the division of labor required, managerial skills and a variety of organizational solutions. The concept of staff functions as opposed to line functions was developed. Staff functions arose out of the newly encountered problems arising simply from the scale of operations. There was a need for raw materials provision (negotiation of purchasing agreements, scheduling delivery, delivery, and supply to craftsmen so as to not interrupt the manufacturing process). There was a need for disposal of finished products (sales, delivery, etc.). Other functions were required, as accounting, locating, hiring and firing of laborers, payroll management, and all those tasks demanding attention so that the line or manufacturing staff could go about the business of manufacturing product unhindered by externalities (Murphy 1998).

The entire mass production process was forced to evolve in concert with technological advance. Any in-depth discussion of these processes enmeshes one in the industrialization process as opposed to the manufacturing process. Suffice it here to note that the successful industrialization process both in terms of mass production processes and the infrastructure to support the workers was necessary to carry forward the closed cycle of technological advance followed by production followed by industrial utilization followed by demand for enhancements followed by technological advance to meet the newly perceived needs.

Manufacturing Processes

During the early days of industrialization when the factories were small and the level of individual craftsmanship was high, the workbench skills of these workers were more important than the scientific knowledge or the intellectual skills which would be demanded in the latter 19th and into the 20th century. In essence the small factory of the early 19th century was still in competition with household manufacturing which had traditionally dominated the manufacturing process. As the factories began to bring together a larger number of handworkers, they were able to effect a minute division of labor and decrease the individual level of skill required. This lowered the wage scales otherwise required of master craftsmen and ultimately reduced the pricing of their products in comparison with household manufacture. Specialization, in turn, allowed the individual worker to concentrate on a single piece of the manufacturing process and to work to streamline not only the effort to produce a given part, but to speed the overall process as well.

Two key manufacturing processes began to emerge. First was the move to interchangeable parts – a goal of Europeans as well as Americans. The process of interchangeable parts and that of machines manufacturing machines were both firmly in place at the dawn of the tractor era. Though it did not precipitate it, the manufacture of tractors benefited enormously from development of the moving assembly line. Early manufacturers of tractors continued the practice of manufacturing one unit at a time, starting at a place on the shop floor and continuing in that spot until the unit was complete. The larger the firm the more assembly points were in operation at any one time. Mass production depended on interchangeable parts, but required the moving assembly line to bring the price of the tractor down to the point where it could successfully compete with a horse on a small, family farm.

STATE OF AGRICULTURE AT THE DAWN OF THE TRACTOR ERA

The period 1800-1900 represented a monotonically increasing period in all aspects of agriculture in the U.S.: number of farms under cultivation, number of draft animals servicing this increased number of farms, development and investment in factory-made farm implements, use of chemical fertilizers, and (not surprisingly) productivity. Leading into the tractor era the basic potentialities of agricultural machinery that were dependent on horsepower had been developed, and agriculture was becoming more and more mechanized and commercialized. (USDA 1999; Letourneau 1993).

The increase in number of farms under cultivation is indicated in Table 9 showing that in the twenty-year period from 1860 to 1880, the number of farms doubled from 2 to 4 million. Note that during this period acreage under cultivation increased by only 57

TABLE 9
NUMBER OF FARMS IN THE U.S., 1860-1880

Year	Farms (000,000)	Acres (000,000)	Average Size (Acres)
1860	2 00	163	81 5
1870	2.66		
1880	4 00	285	71 3

(Letourneau, 1993, 293)

percent as the overall average size of farms shrunk.

Expanding on this trend, Table 10 shows the increase in number of farms on the High Plains. Note that on the High Plains, the number of farms continued to increase until the agricultural recession of the early 1920s. The trend then reversed and continued downward until the number of farms in 1970 was only slightly more than that of 1900.

TABLE 10
NUMBER OF FARMS IN THE HIGH PLAINS
STATES, 1870 -1970

Year	State				
	Montana	Wyoming	Colorado	New Mexico	Total
1870	815	175	1,738	4,480	7,208
1880	1,519	457	4,506	5,053	11,535
1890	5,603	3,125	16,389	4,458	29,575
1900	13,370	6,095	24,700	12,311	56,476
1910	26,214	10,927	46,170	35,676	118,987
1920	57,677	15,748	59,934	29,844	163,203
1930	47,495	16,011	59,956	31,404	154,866
1940	41,823	15,019	51,426	34,105	142,373
1950	35,085	12,614	49,578	23,559	120,836
1960	28,958	9,744	33,390	15,919	88,011
1970	24,951	8,838	27,950	11,641	73,380

(Gates 1977, 118)

A second advantage is improvement in the quality of life. This characteristic was difficult to conceptualize and open to various evaluations over time.

During this period of increasing number of farms, the number of draft animals was also on the rise as indicated in Table 11. From 1860 to 1880, when the number of farms under cultivation doubled, the number of animals increased by 31 percent, indicating increased productivity in terms of animal-hours per acre. The number of draft animals continued to increase until the mid-1920's, then started an ever-increasing

TABLE 11
ESTIMATED NUMBER OF DRAFT ANIMALS
ON U.S. FARMS, 1850-1890

Year	Horses (000)	Mules (000)	Oxen (000)	Total (000)
1850	4,357	559	1,701	8,467
1860	6,249	1,151	2,255	11,515
1870	7,145	1,125	1,319	11,459
1880	10,357	1,813	994	15,044
1890	15,266	2,252	1,117	20,525

(Letourneau 1993, 48)

decline as tractors assumed the work of the draft animals, but it was not until 1954 that the number of tractors exceeded that of draft animals on the farms of America (USDA 1999).

The nineteenth century featured a string of farm equipment developments from the patenting of the first cast-iron plow in 1793, to ready availability of barbed wire by 1874, to use of horse drawn combines on the Pacific coast wheat areas. Naturally, with the introduction of such production-enhancing farm equipment, the investment in such equipment also ballooned. Table 12 shows the dramatic change in farm equipment

TABLE 12
GROWTH IN MANUFACTURING OF AGRICULTURAL
IMPLEMENTS, 1869-1899

Year	Number of Manufacturers	Capital Invested ($)	Product Value ($)
1869	2,067	34,834,600	52,066,875
1879	1,943	62,109,668	68,640,486
1889	910	145,313,997	81,271,651
1899	715	157,707,951	101,207,428

(Letourneau 1993, 37)

manufacture and investment. As the farm equipment industry evolved from a one-off or custom manufacture to a mass production context, the number of manufacturers dropped by two-thirds in the 1869-99 period. At the same time capital investment of such equipment was up by four-fold and product value doubled.

Mixed chemical fertilizers were first introduced in 1850. By the 1890's the annual average consumption of commercial fertilizers had grown to 1,845,900 tons. (USDA 2001)

As production of the nation's food trended more and more toward commercialization and increased investment in equipment, fencing and fertilizers, farm productively, rose accordingly. An effective way to gauge productivity is that of labor-hours required to produce some quantity of a crop. In 1850 it required 90 labor-hours to produce 100 bushels of corn – approximately 2.5 acres. By 1890 the same 100 bushels were produced with the expenditure of only 40 labor-hours – a reduction of 225 percent. Similarly, in 1830, 300 labor-hours were required to produce 100 bushels of wheat - approximately 5 acres (USDA 2001). By 1890 this number had dropped by 600 percent to 50 labor-hours. Similar productivity increases were achieved with other crops (USDA 2001).

Thus the introduction of the steam traction and later gasoline traction engine can be viewed as part of a continuum in the evolution of agricultural technology and practice.

THE ERA OF THE STEAM TRACTION ENGINE

Development

The era of the steam traction engine extended from approximately 1880 until 1924. Production years for J. I. Case Threshing Machine Company, the most prolific of the steam traction engine manufacturers, actually started in 1876 but production did not exceed 300 until 1880. Units were probably built and tested prior to 1876 and possibly as early as 1969, but today no records exist for any such machines. As early as 1870, J. I. Case Company catalogs contained pictures of steam traction engines to be introduced in the future, but it would be six more years before production actually commenced (Erb and Brumbaugh 1993).

Two driving forces were primarily responsible for the steam traction engine's development and popularity. Following the Civil War, homesteaders were flocking to the Rural Heartland and to California. Breaking up the prairie sod was essentially an impossible task using draft animals. Similar situations existed in California, except there the soil was frequently soft or unstable. Second was the drudgery of threshing by hand. J. I. Case and others were manufacturing threshers, but had pretty much exhausted the options for power through use of draft animals. The thresher, stemming the gap between hand methods and the combine, cried for power in the field. Just as steam had brought industrialization to American industry in the 1850s, so to it would bring commercialization to agriculture starting in the 1870s (Halberstadt 2000) of course, having a steam engine in the field demanded new expertise on the part of the farmer. Just as an engineer was required to operate a steam locomotive, so too was one required for a steam traction engine. Further, by its very nature, a steam engine is a high maintenance item, requiring constant attention and repair – thus the new need for a farm hand possessing the skills of a mechanic.

As the need for power in the field became apparent, the initial solution was to mount a steam engine on a wheeled chassis and tow it into the field with a team of horses. These units were used solely for threshing. Their success is demonstrated by a demand for the next development – self propulsion. Here the earliest machines were provided with a drive mechanism, but horses were still used to steer the unit. A stream of technological developments followed. A steering mechanism was added, thus obviating the need for a team of horses. Springs were added so that the steam engine, and especially the boiler, was cushioned from the uneven terrain and poor roads. Spark arrestors were added to the stack. Options were added allowing the engines to use wood or straw and ultimately fuel oil as fuel. The steam engines became smaller and more powerful. Where Case offered a 10 horsepower unit in 1876, 20, 25 and 30 horsepower units were available by 1890, and by 1910 Case was offering a 110 horsepower unit (Erb and Brumbaugh 1993).

Steam traction engines also became safer. Explosions were not uncommon for a variety of reasons including the terrain, the state of metallurgy, and the quality of maintenance. Erb and Brumbaugh (1993, 44) comment that:

> *In 1911, it was estimated that two boiler explosions occurred in the United States every day. During the first six months of 1914, 340 boiler explosions killed 120*

> *people and injured an additional 240 more. Injury and property losses of $250,000 were sustained.*

This propensity to explode explains why the steam traction engines pictured during threshing operations provided power to the thresher via a belt of sufficient length to place the tractor (and hence the boiler) 50 or more feet from the threshing operations. The threshers not only did not want to get blown up, they also did not want their chaff pile to catch fire from an errant spark. As dangerous as boiler operation was, however, more engineer/operators were probably injured attempting to cross bridges. The roads and bridges of the era had been constructed for horses and buggies, and horse drawn freight wagons. When confronted with a 10 to 12 ton traction engine, the bridges frequently gave way, sending the engine and its boiler into a ravine, subjecting the operators to being pinioned beneath the unit and exposed to escaping steam. The problem was so common that operators would go miles out of their way to avoid unsafe bridges, and frequently carried wooden planks for use in spreading the traction engine's weight over a larger area. All of this helps explain why when the internal combustion engine became a viable alternative to steam that it was embraced in a stunningly short period of time (Erb and Brumbaugh 1993).

Production

A surprisingly small number of steam traction engines were made. While many companies dabbled in their manufacture, a mere seven manufacturers accounted for almost 87 percent of the 83,824 total units built. Table 13 shows the production of these seven companies. Note that of the total number built, that J. I. Case Threshing Machine Company accounted for almost 42 percent.

TABLE 13
MAJOR PRODUCERS OF STEAM TRACTION
ENGINES IN THE U.S.

Company	Total Production
J. I. Case Threshing Machine Co	35,838
Huber Company	11,568
Minneapolis	7,198
Port Huron	6,030
Aultman & Taylor	5,870
Geiser	5,180
Harrison	839
Total	72,523

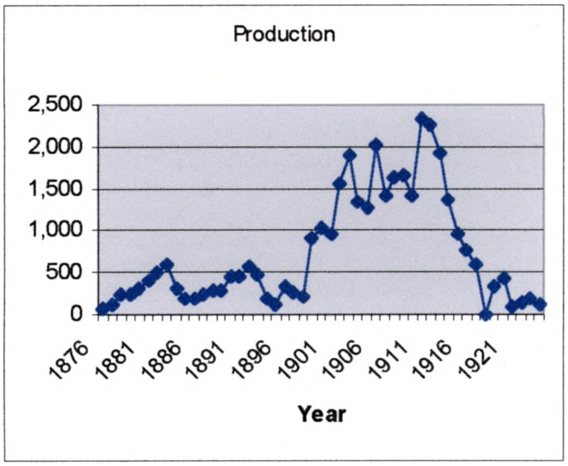
(Erb and Brumbaugh 1993, 69)

Because of Case's dominant position in the industry, its early entry and late departure, looking at its annual production is instructive. Table 14 shows both the annual production and cumulative production by year. Figure 11 shows this same data in graphical form. First, Table 14 and Figure 11 show a rough, but discernable normal distribution curve for the annual production. This would correspond to the classic theory regarding diffusion as exemplified by the sulky plow discussed earlier. Here, however, we present production data as a surrogate for market penetration rather than patents issued. The graphical presentation of the cumulative production shows a much more discernable and rather smooth S-curve or ogive relationship with the normal distribution curve. Maximum production was reached in 1911. Records indicate that 1912 was the year of maximum sales for Case. Thereafter production dropped precipitously until production was terminated in 1924. The drop in demand was caused by two factors. First, the Great Plains had been broken up and plowed. The need for giant tractors capable of pulling a 30 bottom plow no longer existed. Second was the availability of

TABLE 14
CASE STEAM TRACTION ENGINE PRODUCTION, 1876-1924

Year	Case Production	Cumulative Case Production	Year	Case Production	Cumulative Case Production	Year	Case Production	Cumulative Case Production
1876	75	75	1893	482	5,948	1910	1,408	24,277
1877	109	184	1894	199	6,147	1911	2,322	26,599
1878	237	421	1895	127	6,274	1912	2,252	28,851
1879	244	665	1896	346	6,620	1913	1,916	30,767
1880	310	975	1897	262	6,882	1914	1,379	32,146
1881	411	1,386	1898	211	7,093	1915	952	33,098
1882	506	1,892	1899	920	8,013	1916	774	33,872
1883	592	2,484	1900	1,032	9,045	1917	598	34,470
1884	302	2,786	1901	962	10,007	1918	4	34,474
1885	195	2,981	1902	1,574	11,581	1919	346	34,820
1886	182	3,163	1903	1,905	13,486	1920	442	35,262
1887	236	3,399	1904	1,348	14,834	1921	93	35,355
1888	280	3,679	1905	1,286	16,120	1922	153	35,508
1889	297	3,976	1906	2,021	18,141	1923	198	35,706
1890	456	4,432	1907	1,421	19,562	1924	132	35,838
1891	462	4,894	1908	1,645	21,207			
1892	572	5,466	1909	1,662	22,869			

(Erb and Brumbaugh 1993, 330)



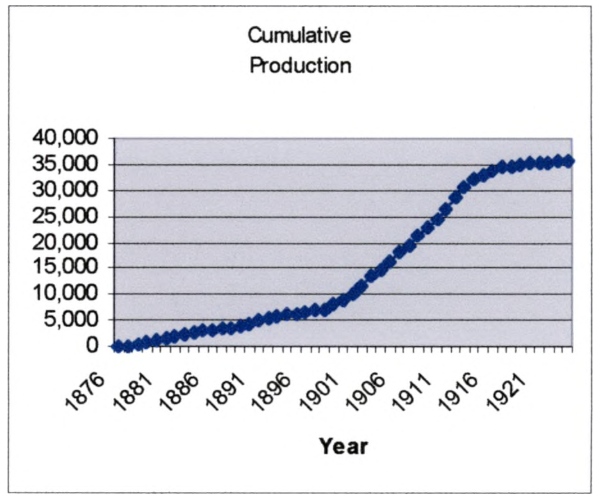


Figure 11. Case production of steam traction engines – annually and cumulatively, 1876-1924.

gasoline powered traction engines. These units were cheaper, more reliable, less dangerous, and required only a single driver as opposed to the steam traction engines which required a minimum of two people. The first production gasoline traction engine was manufactured by Hart & Parr in 1902. By 1912, despite record production of steam traction engines in 1911, Case introduced its first gasoline traction engine. By 1918, Henry Ford had introduced the Fordson, the first mass produced small tractor designed to compete directly with the horse and indirectly with the steam traction engine. This was the last straw, and in 1924 Case was the last manufacturer to terminate steam traction engine production.

Summary of the Steam Traction Engine Era

Steam traction engine development had been in response to the need for motive power in the fields of the United States. Steam traction engines were never considered a competitor to the horse. With the exception of plowing and threshing, horses continued to be the sources of draft power on all the farms having a steam traction engine. Their demise was sealed with the availability of the internal combustion engine. An advertisement by the Waterloo Gasoline Traction Engine Company in1892 summed up the situation. Advantages claimed for the new internal combustion or gasoline traction engine included:

> No possibility of explosion
> No danger of fire
> No tank man and team necessary
> No high-priced engineer required
> No early firing to get up steam
> No leaky flues
> No broken bridges on account of weight
> No running into obstacles as the operator is in front
> No runaway teams on account of steam blowing off.
> No long belt to contend with
>
> (Pripps and Morland 1993, 29)

Though the initial gasoline traction engines were similar to their steam predecessors in appearance and functionality, they represented an alternative to all the problems listed above.

So, in the relatively short span of time from 1876 until 1924, the era of the steam traction engine ran its complete course, production having peaked in 1911. To be sure, many of these large, ungainly, dangerous, labor intensive machines continued in operation for many years – particularly those fitted out for highway construction activity as road rollers.

DEVELOPMENT OF THE TRACTOR INDUSTRY

The tractor industry has evolved and matured as a progression of stages or eras. I define four such stages of tractor industry development and evolution:

The farm implement company as precursor to the tractor manufacturing company - Farm implement companies emerged from independently operated blacksmith operations, generally led by a dynamic individual. Some of these companies began providing motive power in the field in response to the demand for energy to drive the recently invented and introduced implements via the steam traction engine, then segued into the gasoline traction business. Others waited for the gasoline traction engine. Representative of this stage are J. I. Case, and John Deere.

Pioneers in Steam and Gasoline Traction Engines - Pioneering individuals founded companies and entered the tractor manufacturing industry directly. These startup companies were established by true pioneers who provided engineering expertise to their companies in bringing tractor technology to a marketable and useful state. Companies as Gaar-Scott, Advance-Rumely, the

Holt Manufacturing Company, Daniel Best Company, Ford Motor Company, and Hart & Parr Company fall in this category.

Corporate takeovers of pioneering companies and their progeny through acquisition, mergers, and industry shakeout - Some old-line implement companies bought their way into the tractor industry via acquisition of a company with an existing tractor product. Others merged with companies forming an economically cohesive new company where one of the merging companies had a tractor line. Many, many startup companies were forced out of the business as a result of a number of factors ranging from a poor product to under capitalization to bad economic times. Much of this activity occurred during the 1920s and 1930s when the general purpose and row crop tractors made their appearance, mass production forced greater competition, and the Great Depression forced financially strapped companies into merger and acquisition in order to survive. Companies included in this category include Oliver Farm Implement Company, Allis-Chalmers, and Minneapolis-Moline.

Conglomerate acquisition, internationalization and depersonalization of the industry - The ultimate step in the maturation process saw the emergence of conglomerates purchasing tractor corporations, sometimes specializing in agricultural equipment and others acquiring such companies not even tangential to their core businesses. This stage generally had its roots in the economic slowdown experienced in agriculture during the 1980s. Kern County

Development Company, Tenneco, Inc., AGCO and the current incarnation of J. I. Case Corporation exemplify this trend.

THE TRACTOR MANUFACTURERS AND THEIR PRODUCTS

While these stages fall more or less chronologically as listed, the years overlap to such an extent as to become meaningless in defining and understanding the maturation of the tractor industry. Each of the stages described is characterized by discussions of representative companies as listed in Table 7. The presentation of companies is done in alphabetical order. Selection of the companies included here was done on the basis of a representative presentation of the industry as a whole rather than attempting to select the most important companies.

AGCO (Allis-Gleaner Corporation)

Allis-Gleaner (AGCO) is, perhaps, the quintessential example of the international conglomerate era of the tractor industry. Its appearance occurred as the maturation process reached its final stage - 46 years after tractors outnumbered horses on the farms of America. The company was chartered in 1990 when a management buy-out group of Klockner-Humboldt-Deutz AG, KHD, of Cologne, Germany purchased KHD's Deutz-Allis division of Milwaukee, WI. Figure 23 shows a high-level genealogy of the company's subsequent growth through acquisition. Table 15 lists the present corporate divisions and their major product lines.

TABLE 15
AGCO BRAND NAMES AND ASSOCIATED PRODUCTS

Company	Product(s)
AGCO Allis	Tractors. 45 to 225 hp Two-wheel and all-wheel drive
AGCOSTAR	Tractors Articulated four-wheel drive 360 to 425 hp
Black Machine	Appears to have been absorbed into one of the other product lines
Farmhand	Loaders, rotary cutters, estate groomers
Fendt	Vario series A stepless variable transmission (SVT) with infinite speed selection
Fieldstar	Global positioning system (GPS), yield monitoring, variable-rate technology (VRT, mapping (Y-map, A-map), lightbar guidance
Gleaner	Rotary and conventional harvesters
Glencoe	Primary, secondary, and rolling tillage, power ditches
Hesston	Hay and forage equipment – windrowers, balers, rakes,, and conditioners
Landini	Tractors (mostly in Europe) Fifty different models ranging from 43 to 123 PTO hp
Massey-Ferguson	Tractors (16 to 225 PTO hp), riding mowers (14-16 hp), articulated wheel loaders, rotary and conventional combines, combine headers, swathers
New Idea	Round balers, disc mowers, bar rakes, tedder rakes, and manure spreaders
Spra-Coupe	Light-weight ground sprayer
Tye	Conventional drills, no-till drills, and specialty drills
White Planter	Single-frame, pull type planters, forward-fold planters, horizontal-fold, flex frame planters, forward fold planters, two-bar planters, tool-bar planters, center-fill planters, and splitters
White Tractor	Tractors (45-225 PTO hp), loaders
Willmar	Wheel loaders, spreaders,, sprayers

(AGCO 2000)

While the company's history dates only from 1990, the lineage of acquired companies dates back to 1847. During that year, Daniel Massey established Massey Manufacturing Company in Toronto, Ontario. Massey then became Massey-Harris, then Massey-Harris-Ferguson and later Massey-Ferguson. That same year, Reliance Works Flower Milling Company of Milwaukee, WI was formed and its name changed to Allis-Chalmers in 1912. Companies folded into one corporate entity or another and ultimately converging into AGCO include: Garr-Scott & Company of Richmond, IN, Advanced

Thresher Company, Battle Creek, MI, Northwest Thresher Company, Stillwater, MI, and Aultman-Taylor Company, Mansfield, OH (Advance-Rumely), Monarch Tractors, Inc. Springfield, IL, and Advance-Rumely of La Porte, IN (Allis-Chalmers); Universal Tractor Company, Columbus, OH (Minneapolis-Moline); Wallis Tractor Company, Cleveland, OH (Massey-Ferguson); and Hart & Parr, Charles City, IA, and Cleveland Tractor Corporation, Cleveland, OH (Oliver Farm Equipment Company.) During the early 1960s Cockshutt Farm Equipment Company, Ltd of Brantford, Ontario, Minneapolis-Moline Power Implement Company of Moline, IL, and Oliver Farm Equipment Company of Charles City, IA, were purchased by White Motor Company to form White Farm Equipment Company (WFE). WFE was subsequently purchased by Texas Investment Corporation, TIC, of Dallas, TX in 1981, and then by Allied Products Corporation of Chicago, IL in 1985. Allied merged WFE with New Idea to form White-New Idea in 1987. Finally, Allis-Chalmers, was purchased by Deutz AG of Cologne, Germany and organized as Deutz-Allis in 1985. Deutz-Allis was the foundation of the management buy-out to form AGCO. The White-New Idea tractor division was then purchased by AGCO in 1991. Massey-Ferguson was added in 1994. Landini was added and then Fendt in 1998. As shown in Table 15, AGCO Allis, AGCOSTAR, Landini, Massey-Ferguson, and White Tractors are also used as brand names for various tractor lines.

The company went public in 1992 with an initial public offering (IPO) and listing on the NASDAQ. In 1994 they were listed on the NYSE. The stock was adjusted to 59 million shares in 1998. Today AGCO is one of the world's largest designers, manufacturers, and distributors of agricultural equipment. The company markets under sixteen brand names as listed in Table 15 in more than 140 countries through a dealership network of 8,200 full-service dealers (the largest in the industry). First year gross sales in 1990 were $200 million. By 1998 AGCO gross sales reached $2.9 billion worldwide.

And so, from the start-up companies of the mid 19th century in which one or more pioneering individuals demonstrated the true individual entrepreneurial spirit by establishing their own company and directing its product development, growth, and marketing, the tractor industry has segued at the end of the 20th century to the international conglomerate structure whereby, in the case of AGCO, all product lines were acquired through acquisition. AGCO growth is then attained through the combination of international finance, acquisition, product enhancement, and marketing acumen.

Allis-Chalmers Manufacturing Company

Allis-Chalmers the Company

The name Allis-Chalmers has a long history of association with tractor manufacture. The company history falls roughly into the industry eras of pioneers/pioneer families, acquisition, and finally takeover by international conglomerate as shown in Figure 24.

The company traces its origins to the establishment of Reliance Works Flower Milling Company of Milwaukee, WI in 1847. This original company ran into financial troubles in 1857 and was purchased in 1861 by Edward P. Allis at a sheriff's sale. Allis promptly changed the name to E. P. Allis Company. When Allis died in 1889, the company was taken over by his family and one Edwin Reynolds. In 1901 a major merger was effected with Fraser & Chalmers of Chicago, IL, Gates Iron Works also of Chicago, and Dickson Manufacturing Company of Scranton, PA. The new company was renamed Allis-Chalmers, a name which survived until the company's financial troubles of the 1980's ultimately resulted in the sale in 1990 of the agricultural equipment division (including tractor manufacture) to Klockner-Humbolt-Deutz (KHD) of Cologne, Germany. KHD renamed the new division Deutz-Allis (Wendel and Morland 1992).

Allis-Chalmers never got into the steam traction engine business and thus was unfettered with sunk costs and corporate tradition when it decided to get into the gasoline traction engine business. The impetus for this move came after Otto H. Falk, a former Wisconsin National Guard Brigadier General, had taken the reins of a reorganized Allis-Chalmers in 1912. The initial model, developed in-house, was the rather small 10/18, manufactured from 1914-1923. It had a two-cylinder engine powered by either gasoline or kerosene and weighed in at 4,800 pounds. This model suffered from Allis-Chalmers' lack of a countrywide dealership network to supply farm sales and service; Allis-Chalmers being at this time primarily in the flour milling and sawmill supply business (Wendel and Morland 1992). The production run of approximately 2,700 units was modest, but a start.

During the period 1901-1990 two major acquisitions were effected. In 1928 the Monarch Tractor Corporation of Springfield, IL was acquired. Monarch was a manufacturer of crawler tractors (Swinford 1996; Wendel and Morland 1992). Allis-Chalmers used this entrée into the crawler tractor business to ride a wave of activity in crawler tractors in agriculture throughout the 1930s. In 1931 the Advance-Rumely Thresher Company, manufacturer of OilPull™ tractors was acquired. Advance-Rumely's history is itself a story in tractor history as is discussed subsequently and in Figure 22 (Swinford 1996).

Other than the Advance-Rumely acquisition in 1931, no major corporate changes were effected during the Great Depression – the World War II period, or indeed, in the good times following World War II and the Korean conflict. However, when the industry suffered a decline in equipment sales commencing in the 1980s, Allis-Chalmers began a downward spiral ending with bankruptcy and finally acquisition by Klockner-Humboldt-Deutz who then operated in the U.S. as Deutz-Allis. Table 16 shows a count down to the end for Allis-Chalmers starting in 1980. While unique to Allis-Chalmers, the chain of events presents a script played out at dozens of agricultural equipment and tractor companies as they experienced economic disaster and ultimate acquisition, merger, or cessation of operation for reasons not directly associated with the quality of the product.

Advance-Rumely the Company

Advance-Rumely was itself a venerable company, tracing its roots to the 1853 founding of M & J Rumely in La Porte, IN. The brothers Rumely, Meinrad and John, were German immigrants. Their original product lines included pioneering threshing machines, stationary steam engines, portable steam engines, and steam traction engines. As indicated in Figure 22, the M. Rumely Company, still located in La Porte, IN, acquired three companies in 1911 and 1912 including Gaar - Scott and Company, a manufacturer of steam traction engines. In 1913 the company was reorganized, and in 1915 it was reorganized again, taking on its final name, Advance-Rumely. Rumely began manufacture of its OilPull line in 1910 and it was this product line that attracted

TABLE 16
ALLIS-CHALMERS COUNTDOWN TO THE END

Year	Event
1980	Citing an industry-wide decline in agricultural equipment sales, A-C closes its Milwaukee tractor plant and foundry for eight weeks during the summer, laying off 850 of its 2,000 hourly employees Company's total employment is 3,500. Profits were $47 6 million for the year
1981	A-C cited a prolonged siege of record-high interest rates in this capital-intensive business as contributing to plant closings, production cuts, layoffs, and the suspension of common stock dividend payments. Hourly employees were down to 1,600 The firm lost $28 8 million for the year
1982	A-C began to be called "troubled " It froze some wages, cut some salaries, and laid off more workers, reducing the total work force to 2,350 people, of whom 1,450 were production workers The loss for the year totaled $207 million, the largest ever reported for a Wisconsin-based company.
1983	Windell F Bueche succeeded David. C Scott as chief executive officer The loss for the year was down to $133.2 million, roughly 65% of what it was the previous year
1984	A-C continued to cut back It halted the production of tractors and combines It had losses of $103 million
1985	A-C sold its agricultural equipment business, including the Allis-Chalmers Credit Corp for $107 million to Kloeckner-Humboldt-Deutz AG, KHD, of Cologne, West Germany Deutz AG continued tractor operations under the name Deutz-Allis Corp It dropped 11 pension plans and placed them under the care of the Federal Pension Benefit Guaranty Corp retaining 29 other pension plans
1986	A-C sold two office buildings and a parking lot at its South 70th St headquarters to Milwaukee-based $70 Limited Partnership, led by William Orenstein It sold its York, PA hydro-turbine business It was still "staggering financially "
1987	A-C announced a restructuring plan, including a proposal to sell virtually the entire company, leaving nothing but American Air Filter based in Louisville, KY It lost money again in the first quarter - $9.7 million It filed for bankruptcy protection
1988, Jan 4	A-C sells several businesses to Sweden's Boliden AB for $97 9 million
1988, May 24	A-C sells its Power Generation Services operation (pending approval from the U S Bankruptcy Court in New York) to A-C Power Generation Service Acquisition Corp for $14.5 million
1988, June 22	A-C sells its pump business to ITT Corp for $7 1 million
1988, Sept. 21	Allis-Chalmers receives approval to sell companies to A-C Power Generation Service Acquisition Corp
1989, Jan 29	Last employee closes the West Allis plant

(Rumely 1999)

Allis-Chalmers in 1931. An interesting acquisition of Advance-Rumely in 1923 was that of the Aultman-Taylor Machinery Company of Mansfield, OH. Aultman-Taylor itself dating its lineage to before the Civil War, manufactured steam engine powered threshing equipment. Following the acquisition, Advance-Rumely Company sold off the inventory and ceased production – thus quashing the competition in a most effective fashion. Allis-

Chalmers' purchase of the Advance-Rumely OilPull line in 1931 placed it firmly in the internal combustion powered tractor business as a complement to the line of crawlers as a result of the acquisition of Monarch Tractor Corporation in 1928 (Swinford 1996).

So, Allis-Chalmers in its final incarnation had reached that final state as a result of merger and acquisition of some 11 different companies. Its subsequent acquisition by Deutz AG and then AGCO places it in all four of the stages of tractor industry development introduced previously.

Allis-Chalmers and Advance-Rumely Models

During the history of the company, Allis-Chalmers accounted for a number of firsts as noted in Table 17.

TABLE 17
SOME ALLIS-CHALMERS INNOVATIONS

Year	Event
1930s	Allis-Chalmers was one of the first farm tractor companies to use a dry-type air cleaner
1931	Pneumatic rubber tires were first used and sold of Allis-Chalmers tractors
1933	A-C used the first square engine, 4 in bore and stroke in their WC tractor
1939	Positive seal track idlers were announced for A-C crawler tractors.
1948	Power-adjustable rear wheels were first used on the WD tractor
1948	The D-19 diesel was the first agricultural tractor to be equipped with a turbocharger
1956	Power steering was introduced on the WD-45 tractor in

(Wendel and Morland 1992, 60)

Prior to Allis-Chalmers' entry into the tractor business, Advance-Rumely was a major producer. Before the introduction of Ford's Fordson, Advance-Rumely had produced a series of tractors modeled on the old large tractor model. These would include the E, F, H, and G OilPull models introduced from 1910 to 1918 (Table 29). Three of these units were ultimately submitted to the Nebraska Testing Laboratory in 1920. Ranging in weight from the E's 26,000 lbs. to the H's relatively modest 9,500 lbs., these large, slow-moving beasts bore much more resemblance to the steam traction engines than to the tractors of the future. Starting with the Model K, OilPull introduced in 1918 and continuing until independent operations were terminated in 1931, Advance-Rumely introduced an additional twelve models. These ranged from the DoAll's 21.61 Bhp. in 1928 to the 70.16 Bhp. model of 1924. None of these models were equipped with pneumatic tires, and the brake to drawbar ratio extended from a low of about 55 percent to a surprising high of 76 percent, though the number was achieved with the small (3,702 lbs.) DoAll. Kerosene was the fuel of choice for the earlier models, and it was not until the Rumely 6A was introduced in 1930 that a gasoline powered engine was featured.

Figure 12 shows a representative advertisement for one of Advance-Rumely's typical models, the X OilPull. The Model X was one of Advance-Rumely's last models; produced from 1928 through 1930. As Advertised, the X was rated at 40 belt horsepower and 25 at the drawbar. Actually the results of the Nebraska test indicated significantly better results at 50.26 and 37.79 for belt and drawbar. With 2,401 units manufactured, the Model X was the seventh most popular model amongst A-R's models (Rumely 1999). Note in the picture the smooth steel rear-drive wheels, partially accounting for most of the 37 percent drop in horsepower from the belt to the drawbar. Also note the large belt drive wheel immediately forward of the rear wheel. At the front the large, square, oil-cooled radiator was a dominating hallmark of Advance-Rumely OilPull tractors (Rumely

(Rumely 1999)

Figure 12 - A typical Advance-Rumely advertisement for the times, circa 1928.

1999). Because of the exceptional cooling capacity of these radiators, Advance-Rumely was able to advertise directly on the side of the unit that the tractor was:

> *Guaranteed to burn successfully all grades of kerosene under all conditions, at all loads up to its rated brake horsepower.*
> (Wendel and Morland 1992, 32)
>
> An expansive guarantee indeed!

Allis-Chalmers entered the tractor market in 1914 with the introduction of the 10-18. This was a small for the time, 3-wheel tractor weighing in 4,800 lbs. tractor. The model was sold from 1914 until 1923. A modest (at least for 10 years of production) 2,700 units were produced. It was a modest beginning, but at least it put Allis-Chalmers onto the playing field. An additional 26 tests were performed on Allis-Chalmers tractors by 1954.

Perhaps the most notable event in the history of Allis-Chalmers (at least as regards the development of the tractor) was the introduction in 1932 of pneumatic tires on its Model U. The tires installed were manufactured by Firestone and were originally intended as airplane tires. These smooth, 12 x 48 tires carried a recommended 70 psi of inflation. When reduced to 12 psi in the field, the tires provided significant improvement in traction over their steel counterparts. Fuel consumption was reduced, and tractors could operate in one higher gear, thus speeding operations. Of secondary importance, the pneumatic tires provided a much more comfortable ride, reducing operator fatigue. Pneumatic tires soon became standard equipment throughout the tractor industry (Swinford 1996). Prior to the introduction of pneumatic tires, the loss of horsepower from the belt to the drawbar was typically 50 to 60 (and sometimes 70) percent. With pneumatic tires the loss, by the late 1930s, was reduced to approximately 35 to 50 percent. This reduction was probably a significant factor in the demise in crawler tractor usage in agriculture. During the height of crawler tractor popularity in the 1930s, their typical horsepower loss from the belt to the drawbar was generally only 8 to 12 percent. Despite the absence of a horsepower loss factor, but with added weight and cost, crawlers were no longer as appealing as before. The transition to pneumatic tires extended over a multi-year period as indicated in Table 30 where it is noted that a number of models from 1935 until 1938 were submitted for testing with both steel and pneumatic tires. The increase in drawbar horsepower on pneumatic tires was dramatic (on the WC in 1934, horsepower increased from 14.36 to 19.14 with the simple exchange of tire types.

Other than this innovation, Allis-Chalmers models of the 1930s, 40s and 50s reflected the evolutionary trends of the times. Weights remained relatively the same, going down in relation to belt horsepower. All engines during this period were 4-cylinder, varying from 62 to 461 cubic inch displacement. Most Allis-Chalmers models featured distillate, but as early as 1921 the model 15-30/18-30 was equipped to use gasoline. Most models featured a four forward speed transmission with a few of the smaller, later models having 3 forward gears.

A quote from an Allis-Chalmers advertisement in the late 1930s pitching the All Crop model sums up the sales pitch common for the times:

> *The All-Crop is more of a working companion than a cold-blooded machine.* (Wendel and Morland 1992, 68)

Finally, Allis-Chalmers entered the crawler market in 1928 with the acquisition of Monarch Tractor Corporation of Springfield, IL. While changing the logo from Monarch to Allis-Chalmers in 1928, no noticeable change in the product line appeared. Table 44 shows the 26 models submitted for testing between 1924 and 1954. After 1954, Allis-Chalmers continued to submit crawler models for testing, but at an ever-decreasing rate – as was the trend away from agricultural use of crawlers. During the period 1954-64 a total of only ten tests were run on crawlers, but many models were submitted for separate testing with only the fuel option of gasoline or diesel being different.

J. I. Case Corporation

Case the Company

The Case Company has passed through all the stages of development of the tractor industry. The company was founded by a true pioneer in the agricultural implements industry, Jerome Increase Case. The company expanded both through internal growth and acquisition. After family members (J. I. Case's descendants) sold out their interests, the company became publicly owned. Additional companies were acquired, and then Case itself was acquired by a conglomerate. Unique in the industry, however, Case subsequently became independent and continues operations today as J. I. Case Corporation.

J. I. Case entered the threshing machine business in 1842 in Racine, WI. His original products were made of wood. These early machines were designed to operate on animal power, either on the treadmill or the sweep principle. The company grew and prospered, encountering only the routine vicissitudes of collecting debts from farmers in off or low grain price years. In 1852 a windfall was bestowed on Case and the other farm implement manufacturers with the onset of the Crimean War. Grain prices soared and demands for Case's products soared as well. The flood of immigrants from the East to the Midwest kept sales high. However, in 1855 the Crimean War ended and grain prices returned to pre-war levels. Case's entry into the steam traction engine market in 1876 and the dominant position achieved therein has been discussed earlier. Business at J. I. Case Thresher Machine Company continued to do well. By 1897 a company report specified 500,000 tons of iron and 5 million board feet of lumber consumed in manufacturing (Erb and Brumbaugh 1993).

J. I. Case himself was doing so well with his threshing machine company, frequently referred to simply as the *"T. M. Company,"* that he decided to enter the plow business as well. In the same year as the T. M. Company introduced its first steam traction engine, Case entered into a partnership with Ebenezer Whiting to form Case, Whiting Company, also in Racine, WI. By 1878 Case bought out Whiting and the new company continued independent operations as J. I. Case Plow Works (Figure 26). The T. M. Company operated in parallel and harmony with the Plow Works for a number of years. Disputes began to arise between the two companies around 1912. J. I. Case had died in 1891. Various branches of the family had taken over the two companies with the Case family members ultimately selling their shares of the T. M. Company by 1897. By 1900 shares were available publicly. When the T. M. Company purchased the Grand Detour Plow Company in 1919 placing it in competition with the Plow Works, the fortunes of the Plow Company began a downward slide. The agricultural depression of the 1920s did not help and in 1928 the Plow Works Company was sold to Massey-Harris.

Back at the T. M. company, manufacture of steam traction engines and threshers provided the main sources of revenue into the 20th century. However, John Froelich had built a successful gasoline traction engine in 1892, and by 1902 Hart & Parr had become the first company incorporated exclusively to manufacture gasoline traction engines. International Harvester built 200 single cylinder tractors in 1906. Advance-Rumely began tractor manufacture in 1910 with its OilPull line. The handwriting was on the wall for the steam traction engine, and in 1912, the year of maximum sales of steam traction engines at the T. M. Company, their first gasoline traction engine (the Model 60) was introduced (Gray 1975). Actually, Case had built a gasoline traction engine in 1894 in conjunction with William Paterson of Stockton, CA. The machine had many problems, most particularly in carburetion, and the project was dropped. The Model 60 (later advertised as the 30/60) was not all that dissimilar from its steam traction engine predecessors. It weighed 25,800 lbs., and contained many steam traction engine parts (Erb and Brumbaugh 1993).

All things related to internal combustion engines were expanding dramatically during the first two decades of the 20th century. Case bought the Pierce Motor Company of Racine, WI in 1910 and for a time was in the luxury automobile market. Case even dabbled in airplane engines and airplanes themselves, but nothing ever materialized. By 1924 they were out of both the steam traction engine and the automobile businesses (Erb and Brumbaugh 1993).

During the agricultural depression of the 1920s, through the Great Depression, and into the 1950s, Case continued to add companies and introduce new competitive models of their own as the tractor evolved and the nature of the industry matured. In 1928 Case acquired the Emerson-Brantingham Implement Company of Rockford, IL. In 1937 Case added Rock Island Plow Company of Rock Island, IL, and American Tractor Corporation of Churubusco, IN was added in 1957 (Figure 25).

By 1964, however, Case was in trouble. They became a take-over target and succumbed to a conglomerate buyout by Kern County Land Company of San Francisco. In 1967 Case again changed hands, being sold to yet another conglomerate, Tenneco Inc. of Houston, TX. In 1967, with International Harvester struggling, Tenneco purchased that company and merged it with Case in an attempt to salvage one good company from two struggling ones. With yet more corporate turmoil, this time at Tenneco, Case was spun off as an independent company in 1994. Today Case continues tractor manufacture under the Case IH brand and has become the world leader in the manufacture of loaders/backhoes.

Case Models

Case entered the gasoline traction market with the release of the Model 60 (later advertised as the 30/60) in 1912. This 25,800 lbs. unit was basically a steam traction engine with an internal combustion engine substituted. In 1913 the Case Tractor Works was built to produce several sizes of gasoline engine powered tractors. By the time of the Nebraska Testing Laboratory's start-up, Case was in the business. They augmented their line with the purchase of the Emerson-Brantingham Implement Company in 1928, though Emerson-Brantingham submitted only a single model for testing at Nebraska, a 27 Bhp unit of the newer style. This test was number 20, completed in 1920. In all, Case submitted 27 models for testing between 1920 and 1953 (Table 32). These models followed the usual trends. Fuels trended from kerosene in the earlier models to distillate, to gasoline, and finally diesel in the later models. Transmissions inched from two forward gears in 1920-1923 to four forward speeds by 1940. Case models targeted the mid-range market with belt horsepower generally running in the 20s-40s. Only four models were submitted with horsepower greater than 50 Bhp. The largest was the 40/72, introduced in 1923 with a test rating of 91.42 Bhp. However, at 22,000 lbs., the 40/72 provided a lumbering ratio of 240 lbs. per belt horsepower weight to horsepower ratio (Case Corporation 2001).

Caterpillar Tractor Company

Caterpillar the Company

The modern day Caterpillar Tractor Company evolved from an early marriage between two bitter rivals. Benjamin Holt and Daniel Best were both pioneers in the manufacture of steam traction engines for the California market. Each saw the potential represented and turned to the gasoline engine at an early date – Holt sold its first gasoline tractor in 1908, Best in 1913. Each company addressed the California market's problems including large holdings, and frequently peat, soft, or unstable soils. The story of the early Holt-Best competition, however, is complex.

While in his 20s, Daniel Best migrated to the West Coast from Iowa. After a checkered career in a multitude of jobs, in 1888 he witnessed a steam traction engine demonstration by one Marquis de Lafayette Remington. He immediately purchased manufacturing rights for the engine from its Oregon-based developer with the understanding that he would not market his own product in the state of Oregon. By 1889 he sold his first unit commercially, and expanded rapidly thereafter (Leffingwell 1994).

Benjamin Holt migrated west from New Hampshire where his family was in the lumber business – specifically handling hardwoods for wagon manufacture. Benjamin's brother, Charles L. Holt, had preceded him to California where he set up a lumber business similar to the family operation in New Hampshire. Benjamin segued into manufacture of harvesters – particularly a *"side-hill"* unit allowing more efficient land use. From there it was a short route to manufacturing a steam traction engine in 1890. The first unit was nicknamed *"Old Betsy."* The engine was reversible, but had neither transmission nor differential. Betsy weighed in at 48,000 lbs., but could plow 40 acres a day pulling a 30 bottom plow (Orlemann 1998; Leffingwell 1994).

A problem for both Holt and Best was the nature of the soils encountered by their steam traction engines. When these behemoths (frequently weighing in at 25,000 plus lbs.) were used on soft, peat, or unstable soil they tended to bog down and become mired in the fields. Both pioneers experimented with extra wide rims (some in excess of ten feet per wheel) to spread the weight over a larger area. This helped, but was still not satisfactory. In 1904 Benjamin Holt began experimenting with substitution of a set of tracks made from malleable link belts in lieu of rear drive wheels. A photographer taking pictures of the tests randomly commented that the movement of the tracks reminded him of a caterpillar. Holt, recognizing a catchy marketing phrase when he heard one, immediately adopted the name for his new creation (Orlemann 1998).

Both Holt and Best began experimenting with gasoline engines by early in the 20th century and by 1908 Holt had sold a number of units. However, by 1906-07 the two companies had became embroiled in lawsuits and counter suits over accusations of patent infringement. By this time Daniel Best was in his 70s and determined to end the legal stalemate by selling out to Holt. This was accomplished in 1908 with the proviso that his son C. L. (Clarence Leo) Best be appointed president of a new manufacturing facility at San Leandro, CA. About this time the Colean Manufacturing Company of East Peoria, IL was encountering hard times and Holt's company purchased the struggling company, moved the corporate headquarters to Peoria, and in 1910 changed the name to Holt Caterpillar Company. At the same time *"Caterpillar"* was trademarked for the company's products (Figure 27).

From this point onward the company acquired companies and spun off partnerships as it entered new product lines and sought to take advantage of new marketing opportunities in disparate countries and regions of the world. In 1928 Caterpillar purchased the Russell Grader Manufacturing Company of Stephen, MN in order to jump start their entry into the emerging market for road graders as the U.S. moved into road building for the expanding population of personal automobiles (Orlemann 1998). In 1930 the Full Crawler Company of Milwaukee, WI was purchased. Shortly thereafter, Caterpillar redoubled their commitment to the agricultural crawler tractor market. From 1932 until 1936 Caterpillar submitted an incredible 57 models for testing at the Nebraska Tractor Tests, many of which were powered by the newly emerging diesel engines (Wendel 1993). In addition to crawler tractors, Caterpillar became a major manufacturer of bulldozers and loaders. Success in the industrial implements markets plus limited opportunities in agricultural crawler tractors aimed Caterpillar more and more toward the heavy industrial implement market. Entry into these markets was frequently financed by internal development, though as mentioned above, Caterpillar entered the motor grader market via purchase of Russell Grader Manufacturing Company. By the 1940s Caterpillar internally developed its own scraper line to replace previous marketing arrangements with such companies as R. G. LeTourneau. In the late 1950s they entered the front-end loader and backhoe markets, again through internally developed product lines. By the 1960s Caterpillar entered the large hauler market and by the 1970s they were manufacturing hydraulic excavators. In 1962 Caterpillar announced a 50-50 joint venture with Mitsubishi to build Cat products, specifically tracked dozers, loaders and wheel loaders for the Japanese market, thereby sidestepping Japanese import restrictions. Starting in the 1970s DJB Engineering of Peterlee, England began manufacture of a line of articulated trucks made almost exclusively from Caterpillar components. Many Cat dealers carried these vehicles as one of their product lines. In 1996 Caterpillar purchased the successor company, Brown Group Holdings, so that the articulated truck line was wholly Caterpillar. In 1997 they purchased Lucas Variety PLC to acquire the Perkins Engine product line. Finally, in 1998, Caterpillar secured ties to the Australian market through a joint venture with Elphinstone Pty. Ltd. of Tasmania to manufacture underground mining equipment. In the past few years Caterpillar has returned to the agricultural market with an emphasis on diesel powered tractors, but with crawler tracks made of a rubber composite. This development allowed for better speed, lighter weight and less wear on roads when the tractor was out of the field (Orlemann 1998).

Thus two pioneering companies in the steam traction agricultural market merged, and transitioned into the gasoline traction market. The company moved aggressively in the agricultural crawler tractor market during the 1930s, segueing into diesel power. During the 1940s and later the company shifted its focus away from agriculture, and concentrated almost exclusively on heavy equipment for industry – becoming an international company in the process. Recently they have returned to the agricultural market with products featuring composite treads rather than the traditional steel treads. Caterpillar is one of the few companies remaining in the agricultural tractor business continuing operations as an independent manufacturer since its founding and entry into the tractor business.

Caterpillar Models

Examining Table 33, it is immediately apparent that the height of Caterpillar's activity in the agricultural crawler market came in the 1930s. Of the 50 models submitted for Nebraska testing, 33 of these tests occurred in the decade of the 30s. As the general purpose tractor became more popular in agriculture, Caterpillar shifted its focus toward the industrial sector of the market. By the nature of the beast, crawlers are heavy, and since they are heavy anyway, horsepower ratings tend to be high. Of the 50 tests, 24 were performed on models with a tested belt horsepower rating of 50 or better, with the highest being the D-8 model in 1940 rated at 127.93. Fuels shifted from gasoline and distillate to a dominance of diesel by 1933. Larger horsepower models tend toward more forward gear options, and this is true of Caterpillar models. Similarly, speeds with crawlers tend to be much slower than with conventional tractors. Common maximum speeds for Caterpillar units were in the 3.6-5.1 mph range. Weight to horsepower ratios also tend to be high. The Diesel Thirty Five model at 92.85 Bhp carried a 345 lbs. per horsepower ratio. The D-8 tested in 1941 showed 370 lbs. per horsepower using the drawbar rating (only one supplied).

Cockshutt Farm Equipment Company, Ltd.

Cockshutt the Company

Cockshutt is discussed here because of its easy classification in two stages of tractor industry development. It was ultimately purchased and absorbed by White Farm Equipment, and it was the only Canadian farm implement company to make any significant contribution to the U.S. tractor market (the Massey and Harris companies started out in Canada, but migrated to the U.S. as operations expanded).

The Cockshutt corporate history commenced with the establishment of Brantford Plow Works in 1877 as shown in Figure 28. The company remained exclusively in the implement business until 1924. From 1924 until 1928 Cockshutt became the Canadian distributor of Hart & Parr tractors. Then from 1928 until 1933 Allis-Chalmers tractors were sold in Canada under the Cockshutt name. In the meantime, Hart & Parr in 1929 had merged with three other companies to form Oliver Farm Equipment Company. Starting in 1934 Cockshutt sold Oliver tractors under the Cockshutt name. At this time Cockshutt and Oliver tractors were identical save for color – green for Oliver and red and cream for Cockshutt. World War II caused a hiatus in tractor manufacture and Cockshutt devoted its total efforts to war production, manufacturing such diverse items as ambulance bodies and hand grenades. Finally, it 1946 the company began manufacture of its own tractor, the Model 30 (Cockshutt Shed 1999; Pripps 1994). The Model 30 was manufactured between 1946 and 1956 with 37,000 units produced. In 1957 English Transcontinental Company purchased the Cockshutt Plow Company operations and continued Canadian operations under the name Cockshutt Farm Equipment Company. With the economic downturn in the late 1950s, Cockshutt became the target of corporate raiders who began selling off parts of the company. In 1961 White Farm Equipment Company purchased the harvester/combine lines. By 1962 final operations were shut down, and the company ceased to exist (Cockshutt 1999; Cockshutt Shed 1999).

Thus the company traced its roots to an old-line implements company. Throughout the life of the company members of the Cockshutt family were directly involved in corporate operations ranging from the founder, James G. Cockshutt to Ashton Cockshutt, President of the Brantford Coach and Body at the time of the buyout. Somewhat different from others, Cockshutt eased into the tractor business by first marketing another company's products, then marketing a brand name manufactured by another company, and finally manufacture of its own product line. In the end Cockshutt was acquired by a conglomerate, White Farm Equipment Company, which was in turn acquired by the ultimate agricultural equipment conglomerate, AGCO (Figure 28).

Cockshutt Models

As indicated in Figure 28, Cockshutt first marketed Hart & Parr, then Allis-Chalmers, then Oliver tractors at various times between 1924 and 1946. At that point, using their own name, they submitted four models for testing at Nebraska until 1953. These models ranged from 30.28 to 52.18 Bhp. The original model tested, Model 30, was the biggest success with over 37,000 units sold between 1945 and 1956. Only one model used diesel fuel, the remaining four ran gasoline. Weight to belt horsepower ratios tended to be quite good with numbers in the 120 lbs. per belt horsepower range (Table 35).

Deere & Company

Deere the Company

Deere & Company is unique among all the agricultural implement companies that segued into tractor manufacture. The company originated in 1843 as Grand Detour Plow Company of Grand Detour, IL. Today it remains under the name Deere & Company as one of two surviving U.S. manufacturers (the other is Caterpillar) operating independently during its entire history. Control of the company remained in the Deere family lineage until the retirement of William Hewitt, who was the son-in-law of John Deere's great-grandson, and the son of Charles Deere Wiman. Hewitt was president from 1955 until 1964 and Chairman from 1964 until 1982. (McMillan and Jones 1988; Deere History 1999; Pripps and Morland 1998).

John Deere was born in Rutland VT in 1804, the son of a tailor. He completed an apprenticeship as a blacksmith in 1825, then went into business for himself, soon specializing in tool manufacture. He migrated to Grand Detour, IL at the age of 32 where he immediately set up a blacksmith shop and started securing local trade. His big break from the pack came when he used a broken saw blade from a local sawmill to make a plowshare (Pripps and Morland 1993). Prior to this time wood and then cast iron had been used in making plowshares. In fact, it was not until 1819 that Jethro Pugh patented a cast iron plow (USDA 2001). Cast iron by its nature is rough and contains surface imperfections known as blowholes. It does not take a polish and is subject to rapid oxidation (rusting). The rough surface on cast iron plows can quickly accumulate mud, requiring that the farmer stop plowing, roll the plow on its side and scrape off the mud with a scraper not unlike a modern day automobile windshield ice scraper. Deere's concept that a steel plowshare would scour and indeed polish itself in the process of operation turned out to be correct. Gone was the constant interruption in plowing to clean the share (McMillan and Jones 1988). Deere's company flourished and by 1847 he was manufacturing 1,000 steel plows per year. In 1848 he moved the operations to Moline, IL where he had a more direct access to steel supply from St. Louis. The company continued in the plow business, and in 1912 expanded into the harvester business. Table 18 shows the production figures for Deere for the fiscal years 1899 and 1909. Deere was firmly in the implements business along a broad front.

TABLE 18
DEERE & COMPANY PRODUCTION,
1899 AND 1909

Implement	1899	1909
Small Cultivator	207,171	469,696
Wheeled Cultivator	295,799	435,429
Disk Harrows	97,261	193,000
Other Harrows	380,259	507,820
Disk Plows	17,345	22,132
Shovel Plows	103,320	245,737
Steam Plows	207	2,355
Wheel (Sulky) Plows	135,102	134,936
Walking Plows	819,022	1,116,000

McMillan and Jones 1988, 11)

At the same time, a number of companies were expanding their product lines and becoming what were then known as *"long line"* implement companies. Notable among these were International Harvester, J. I. Case, and Massey-Harris. To stay competitive and not become a takeover target, Deere would have to expand into the tractor business. Deere first attempted an entry through internal development, creating the Dain tractor (developed under the guidance of board member Joseph Dain). Dain died in 1917 and with him went the driving force behind this early attempt to enter the small tractor market. Deere & Company had initially envisioned the Dain tractor as entering the market with a selling price of $700. However, when it was completed, the price was $1,700, and was priced out of the target market (McMillan and Jones 1988). By 1918

Henry Ford was producing the Fordson, selling for $785, with production exceeding the output of all the competition combined.

In 1918 Deere & Company bought Waterloo Gasoline Traction Engine Company of Waterloo, IA for $2.35 million – manufacturers of the Waterloo Boy tractor. Waterloo Gas Traction Engine Company was itself the descendant company if John Froelich who is credited with construction of the first successful gasoline traction engine in 1892 (McMillan and Jones 1988). Deere's newfound enthusiasm for the tractor can, perhaps, be best encapsulated by a quote from W. L. Velie of Deere and Company in 1918:

> *I think it is safe to eliminate the horse, the mule, the bull team, and the woman, so far as generally furnishing motive power is concerned.*
> (Pripps and Morland 1997, 11)

From 1918 onward, Deere was a major player in the tractor business. Table 19 shows the market share held in 1929 and 1935 by the major long line companies. Note that Ford had dropped U.S. tractor manufacture in 1928. This was ostensibly to clear

TABLE 19
PERCENTAGE OF TRACTOR SALES BY MANUFACTURER, 1929 AND 1935

Manufacturer	1929 Sales (Percent)	1935 Sales (Percent)
International Harvester	52	50
Deere & Company	21	25
J I Case	8	7
Oliver	8	4
Minneapolis-Moline	4	4
Massey-Harris	4	1
Allis-Chalmers	3	10
Others		2

(Letourneau, 1993, 86; Pripps and Morland 1993, 45) production lines for manufacture of the Model A Ford automobile, but in reality the Fordson technology had been surpassed and Ford was not at that time prepared to invest the requisite resources to maintain a competitive position in the U.S. tractor market.

Acquisitions were few and mergers non-existent between Deere's entrance into the tractor market in 1918 and the present. In 1929 the firm did its part for the war effort by manufacturing 75 mm cannon shells at a new plant whose construction was subsidized by the Army. This plant in Dubuque, IA would shift postwar production to tractors and driveshafts (Pripps and Morland 1998). Lindeman Power & Equipment Company of Yakima, WA was acquired in 1946 (Figure 30).

Deere remains in operation today as an independent manufacturer of tractors, still operating out of facilities and company headquarters in Moline, IL (Pripps and Morland 1998).

Deere Models

Deere and Company jump-started their entry into the tractor business in 1918 via the purchase of the Waterloo Gasoline Traction Engine Company of Waterloo, IA, makers of the respected Waterloo Boy line of tractors. Waterloo Boy was the company established by John Froelich after his successful demonstration of a gasoline traction engine in 1892. After then getting out of the tractor business (concentrating on stationary internal combustion engines), Froelich left the company. By 1912 they were again manufacturing tractors. Table 47 shows some information on these models, though they predate the Nebraska tests. Of significance in the table is Waterloo Boy's concentration on 2-cylinder engines.

With the acquisition of the Waterloo Boy tractor line, re-branded Deere, the company was in business. Deere did not submit any models for testing at Nebraska until 1924 with the submission of the Model D (test number 102), but thereafter their production of successive models was prodigious. By 1954 they had submitted 37 models for testing (Table 36). As indicated in Table 19, they achieved second place in 1929 with 21 percent of the U.S. market and upped this number to 25 percent by 1935.

The most significant thing about Deere tractors of this era was their continued allegiance to the 2-cylinder engine. Its distinctive sound is obvious to anyone familiar with tractors. The nickname *"Poppin Johnnie"* immortalized these machines and Deere in the lore of tractor development. Incredibly, the Model D was in production from 1924 until 1953. These were large engines despite having only 2 cylinders. Displacements of 465 cid or better were the norm. All these units featured either kerosene or tractor fuel (a fuel between kerosene and gasoline as regards heating value). Weight to horsepower ratios were high. The Model D tested in 1940 rated 267 lbs. per horsepower. Ratios of drawbar to belt horsepower started at 55 percent in 1924 operating on steel wheels, but this improved to 80 percent in 1940 on pneumatic tires.

Other than the 2-cylinder models, Deere produced a broad range of models with belt horsepower ranges from the upper teens to the mid-40s. Fuel usage tended from distillate or fuel to gasoline and ultimately diesel. Weight to belt horsepower ratios tended toward the 140-150 lbs. per belt horsepower, but tended higher with the larger models as the Model 70 in 1953 with a 200 lbs. per belt horsepower ratio. Drawbar to belt horsepower ratios were consistently in the 80 percent range. This was true even on the heavier models.

Deutz AG

Deutz AG (formerly Klockner-Humboldt-Deutz AG (KHD)) is included in this thesis, despite its primarily European heritage and operations for three reasons. First, the history of the company includes participation by some of the true pioneers of the internal combustion engine/automobile industries. Second, Deutz has a long history of tractor manufacture whose development efforts have undoubtedly been influenced by the pioneers noted above. And third, the company acquired the farm equipment division of Allis-Chalmers and operated it as Deutz-Allis for a period of time prior to its sale to AGCO (Deutz 2001; AGCO 2001).

Nicholaus August Otto (1832-1891) and Eugen Langen (1833-1895) co-founded the company, N. A. Otto & Cie in 1864 in Cologne, Germany (Figure 31). Early company operations were focused on development of the atmospheric gas engine. By 1872 the company experienced its first of many name changes and became Gasmotoren-Fabrik Deutz, GFD (Deutz History 2001).

Also in 1872, Gottlieb Daimler (1834-1900) was hired as engineering director. He, along with Wilhelm Maybach, participated with Otto in development of the internal combustion engine. Previous physical and technical barriers of 3 hp, and the requirement that fuel be supplied by fuel town gas and thus rendering the engine immobile, had spurred development of the four-stroke internal combustion engine. Otto completed design of his engine in 1876 and was awarded a patent on its development in 1877 (patent DRP 532). This patent would, of course, stay in effect internationally for the next 20 years, leading to the flurry of activity regarding internal combustion engines at the end of the century. By 1882 Daimler and Otto were at odds and Daimler and Maybach left to pursue development of a lightweight, high-speed engine operating on gasoline. Having placed one of their engines in a horse carriage along with a four-speed transmission and belt-drive mechanism, Daimler and Maybach established Daimler Motoren Gesellschaft in 1890 (Deutz History 2001).

Other pioneers of automotive and internal combustion engine development associated themselves from time-to-time with GFD. Somewhat in parallel, Karl Benz had formed Benz & Co. in 1883 along with Max Rose and Friedrich Wilhelm Esslinger. After Gottlieb's death in 1900, the Daimler and Benz companies merged in 1926 to form Mercedes-Benz. *"Mercedes"* was the name of one Emile Jellineks' daughter, Jellineks having acquired marketing rights to the car in Austria-Hungary, France, Belgium and the U.S. (Deutz History 2001). At this same time in 1892, Rudolf Diesel (1858-1913) offered the acquisition of his diesel system to GFD. The offer was rejected. By 1896 Deutz had manufactured the first internal combustion engine powered mining locomotive. In 1914, the 50th anniversary of the company, there were 4,100 employees. The year 1926 included the production of Deutz first diesel tractor. World War II was hard on Deutz. By the end of the war, 74 percent of the plants in the Cologne area had been destroyed. However, by 1950 annual production had been restored to 10,000 tractors and crawlers (Deutz History 2001).

The company continued to grow and prosper during the post war period. In 1964 there were 32,000 employees. By 1972 the company had produced its 500,000th tractor since production started in 1926. By the 1980s, what was then known as Klockner-Humbolt-Deutz was able to take advantage of the agricultural slowdown in the

U.S. In 1985, the agricultural division of Allis-Chalmers was purchased and established as Deutz-Allis. The sale, including the Allis-Chalmers Credit Corporation, was completed for $107 million. However, what goes around comes around. By 1989 KHD was suffering its own financial troubles thanks to scandals regarding the creative accounting practices of some KHD subsidiaries. KHD sold off the Deutz-Allis subsidiary to a management buyout group who promptly assumed control as AGCO. Corporate headquarters were established in Duluth, GA.

Additional corporate acquisitions and spinoffs characterized the 1990s. During one such reorganization in 1996, the company was renamed Deutz AG – the corporate name in use today (Figure 31).

Ford Motor Company

Ford the Company

It is difficult to discuss the development of the tractor within the Ford Motor Company because Ford presented an anomaly within the burgeoning industry in a number of aspects:

> Ford was the only predominantly motorcar company to get into and stay in the tractor business in any meaningful way.
>
> Ford never developed or marketed its own line of implements to complement the tractor as was the custom among the manufacturers that sprang from the agricultural implements industry.

Ford introduced the moving assembly line, previously developed for manufacture of Model T automobile, to the manufacture of tractors.

Ford tractors were significantly influenced by two of the true pioneers of the tractor industry: Henry Ford and Harry Ferguson. Many companies were influenced by one pioneer; others by none. Ferguson, of course, had significant impact on several different firms.

Ford produced and marketed a single tractor model (at any one time) from the inception of the Fordson F in 1918 until production of the 8N was discontinued in 1952. Some variations on this theme existed in the Cork (Ireland) and Dagenham (UK) operations.

Ford Develops the Fordson

Henry Ford's personal involvement with tractors began in 1906. Many authors attribute this early interest to his distaste, carried forward from childhood and as a young man, for plowing first on his father's and then his own farm (Ford 1923; Sorensen 1956; Pripps and Morland 1997, 1998). This interest never flagged, though for a number of years it resulted only in experimentation – his major activity being the manufacture of cars, and in particular the Model T.

By 1916 Ford had spent about $600,000 of his own money on tractor research and experiments, and he had prototypes in test. At this point the British Ministry of Munitions, MOM, was desperate for motive power in British fields. German and Turkish war activities had drastically reduced Britain's ability to import grain. Draft animals could not be produced fast enough and according to the British Board of Agriculture there were only 500 tractors in Great Britain in 1914. A government purchasing committee was impressed with the Ford prototype and ultimately negotiated a contract for 6,000 Ford tractors for immediate delivery at $700 per unit. Ford went into a crash development program to move from prototype to production model. Finally, in 1917 the first 254 of the new *"Fordsons"* were delivered. From here the Fordson went into production on the Ford moving assembly lines at the River Rouge plant, and production figures for the first eight years of Fordson production are shown in Table 20. Thus a

TABLE 20
FORDSON TRACTOR PRODUCTION, 1917-1925

Year	Units of Production *
1917	254
1918	34,167
1919	56,987
1920	67,329
1921	35,338
1922	66,752
1923	101,898
1924	83,010
1925	104,168
Total	549,903

* U.S. production only. Does not include Cork and Dagenham.
(Williams 1992b, 122)

major automotive manufacturer was now in the tractor business and had arrived there entirely through internal development and funding (Pripps and Morland 1997). Because of this history, and Ford's virtual lack of mergers and acquisitions, the genealogy shown in Figure 33 includes more historical events and fewer corporate alterations than other companies.

Two related aspects of the Fordson were unique at its inception. First, manufacture was initiated on the Ford Motor Company moving assembly lines. These moving lines were the result of Ford research starting in 1913 and developed over the period from 1913-1918. By the time Fordsons began moving down the assembly lines, Ford already had experience manufacturing 2.8 million Model Ts. Second, Ford had addressed an untapped market with the Fordson. Prior to this time, the steam traction then the gasoline traction engines were built for the big fields of the large farmer, generally in the prairies of the Rural Heartland. These tractors were behemoths, frequently weighing in at 10 to 20 tons. They were intended to perform specific tasks, principally plowing and threshing, on a grand scale. Only a very small number of the total farm population had a use for these giants, or could afford them. The Fordson was designed to attract the small-farm market, and work in direct competition with draft animals. The Fordson was designed to be every man's tractor. It was small, weighing only 2,700 lbs. This compared with Deere's Waterloo Boy's 6,000 lbs., or the 8,700 lbs. of the Titan. It was inexpensive. The original list price was $785.00. Originally not taken seriously by the other manufacturers because of its light weight and diminutive size, the Fordson was an immediate success with production in 1918 of 34,167 units. By the time U.S. production stopped in 1928, 747,572 (including Cork and Dagenham production) units had flooded the market, and for a number of the production years, Ford was producing more that 50 percent of the entire U.S. tractor market.

By 1927 when Model T production was terminated, Ford had produced a total of 15,007,033 Model Ts. All this is by way of indicating that though Ford had produced more than half of the tractors in use by 1928, the company had also produced more than half of all the automobiles on the highways and byways of the United States. So, while Ford was the dominant producer of tractors, their production represented only 4.7 percent of the cumulative production of the company by 1928. Similarly, 1923 production figures (the year of maximum production of Model T's) indicated that Fordson production was again 4.7 percent of total units produced (cars and tractors combined). Obviously, Ford was in the automobile production business. Tractors were personally important to Henry Ford, but a corporate sideline in terms of automobile production and revenues (Leffingwell 1998; Pripps and Morland 1997; Williams 1992b; Ford History 1999).

The Tractor Price Wars

Next in the history of the Fordson were the tractor price wars of the 1920s. When the agricultural depression hit, tractor sales plummeted. All the manufacturers were stuck with large inventories and an abundance of assembly line capacity. Ford's response was to clear his inventory by slashing prices. From $785 the price was reduced to $620. As other manufacturers followed suit, the Fordson price was further reduced to $395. The tactic worked. By 1922 production was back to the 66,000 level of 1920 and by 1923 Fordson production exceeded 100,000 units (Table 20). Many companies with fewer financial resources were not so fortunate. In 1920 there were 166 tractor manufacturers listed in *Farm Machinery and Equipment Magazine*. Total production was 200,000 units of which Ford produced 67,000. By 1929 production had recovered to 1920 levels, but there were only 47 manufacturers listed (Pripps and Morland 1998). The market breakdown, however, was very different. Ford had closed down production of the

Fordson and temporarily abandoned the U.S. market. By 1929 International Harvester had taken over the dominant position in the market with more than a 50 share (Table 19).

Henry Ford and Harry Ferguson

Production of the Fordson, however, continued at Cork, Ireland and Dagenham in Great Britain. The units produced were Fordsons, but they continued evolving over time. As the Great Depression began to retreat in the U.S., Henry Ford began to experiment with a new tractor series. Prominent among the experiments was use of an 85 hp V-8 engine from a 1937 Ford truck. Shortly Harry Ferguson was to enter the picture and change the way farmers used their implements.

Henry George *"Harry"* Ferguson was an Irish-born engineer. Starting in 1917 he spent the next 20 years struggling to perfect a concept of integrating the agricultural tractor and the implements being used into a single unit rather than simply dragging the implement behind the tractor. Ferguson was a complex man. Pripps and Morland (1997, 54) quote Ferguson's biographer, Colin Fraser, with the following description. Ferguson:

> *...combined extremes of subtlety, naivete, charm, rudeness, modesty, largess and pettiness; and the switch from any one to another could be abrupt and unpredictable.*

It was these complexities that undoubtedly led to Ferguson's unique dealings first with David Brown, then Ford and finally Massey-Harris. By 1937 he had perfected the Ferguson system. This system essentially consisted of a three-point, hydraulically operated linkage system whose mechanics forced the weight of the implement and its load downward in front of the rear axle. This provided greater traction as well as negating the rollover (actually a backward flip) difficulties of previous tractors (136 such deaths had been reported for the Fordson alone by 1922 (Harry Ferguson 1999)). By the late 1930s he had established a relationship with the David Brown organization (Figure 29), and was manufacturing a small number of Ferguson-Brown tractors featuring the Ferguson system. In 1938 he managed to schedule a demonstration of the system with Henry Ford at Ford's estate, Fair Lane. The demonstration was a success. Ford was impressed with the three-point linkage and the extra pulling performance achieved. He was intrigued with the idea of a new line of Ford tractors equipped with the Ferguson system. On the site of the demonstration, Ford and Ferguson entered into a discussion leading to the infamous *"Handshake Agreement."* Pripps and Morland (1992, 9) describe the negotiations as having progressed thusly:

> *"You haven't got enough money to buy my patents," Harry Ferguson bluntly told Henry Ford. Ford was by the by the richest man in the world in 1938.*
>
> *"Well, you need me as much as I need you," retorted Ford, "so what do you propose?"*
>
> *"A gentleman's agreement," explained Ferguson. "You stake your reputation and resources on this idea. I stake a lifetime of design and invention – no written agreement could be worthy of what this represents. If you trust me, I trust you."*
>
> *"It's a good idea," said Ford. And with that the two men stood and shook hands.*

Pripps and Morland (1992, 9) then go on the say:

> *Thus was born an agricultural concept that would revolutionize farming. Not only is the squat, compact, insectlike tractor, with its integral implements, still very much in evidence fifty years later, but virtually every farm tractor built since the patents ran out or could be circumvented has embodied the Ford tractor's principal element: the three-point hitch.*

During the ensuing years Ford manufactured the Ford N series featuring the Ferguson system. These units were frequently referred to as Ford-Ferguson and carried an emblem on the front specifying Ferguson System. Going into World War II the N series became designated as 9N and 2N for the model years 1939 and 1942.

The war years showed little production and no particular evolution. Henry Ford retired in 1945 and his second son, Henry Ford II, was named president of Ford Motor Company. In 1946 Ferguson was notified that Ford was abrogating the handshake agreement and continuing manufacture of a new N-series tractor on its own. Ferguson promptly sued for $340 million alleging patent infringement. Henry Ford Sr. died in 1947 at the age of 83. The suit was ultimately settled in 1952 with Ford paying Ferguson $10 million. By this time the 8N, introduced in 1948, had been a huge success without participation by Ferguson, and Ford engineers had managed to work around the Ferguson patents to create a uniquely Ford system. The handshake agreement was at an end.

The End of the Ford Tractor

In 1956 the Ford Motor Company went public through an IPO and was listed on the NYSE. No longer were Ford operations run at the discretion of the Ford family. The company became less and less Ford dominated as Henry Ford II resigned as president in 1979 to become Chairman and CEO. By 1980 he had retired completely. In 1985 Ford acquired the Sperry New Holland Company of New Holland, PA. The name was changed to Ford New Holland with this name appearing on implements sold through the Ford tractor distributorships. In 1990 Ford and Fiat of Italy merged tractor operations from Ford New Holland and Fiat GeoTech to form New Holland GeoTech with Fiat holding 80 percent of the new company. The agreement called for the Ford name to be replaced by New Holland on tractors starting in the year 2000. This was accomplished and today the former Ford dealerships operate as New Holland (Williams 1992b; Sanders 1996; Ford History 1999; Pripps and Morland 1992, 1997).

Thus Ford took its own path through the maturation of the industry. The tractor manufacturing arm of the Ford Motor Company remained under control of the pioneer until 1945. Family control was maintained until 1979. A brief, but extremely important, combining of forces between the Ford Motor Company and Harry Ferguson (it was not really a merger) was in effect from 1938 until 1947. In 1990 tractor operations became part of a new company as a result of a merger, and today the Ford tractor no longer is marketed under that venerable name (Figure 33).

Ford Models

The Ford models are easy to discuss since there were so few of them during the period of interest. From the original Fordson introduced in 1918, until the NAA (Golden Jubilee) in 1953, there were only eight models submitted for testing at the Nebraska Testing Laboratory (Table 38). A total of 14 tests were run with several models submitted for two tests. The 8N was submitted for three.

The two models having significant and lasting consequences for the farmer and tractor industry have been discussed earlier. First was the introduction of the Fordson in 1918. This tractor was introduced in direct competition with the horse for the first time. Second, the Ford Motor Company began, from the start, manufacturing the Fordson on a moving assembly line similar to the ones introduced for the Model T. These two concepts opened up a new market for the tractor while at the same time forcing the price down to an affordable level for the small farmer. A secondary consequence was the forcing of consolidation within the industry and the elimination of many smaller manufacturers.

The second model with great consequences for the industry was the introduction of the Ferguson system, 3 point, hydraulically operated implement hitch. This innovation made the tractor safer, improved traction and productivity and led directly to standardization within the industry of the 3 point hitch as the common attachment configuration for all trailed implements. Gone was the need for a farmer to buy a new set of implements when replacing a tractor.

A number of trends may be observed in Table 38. Brake horsepower increased slowly until the introduction of the NAA and the Fordson Major when a significant increase is noted. The two models presaged a shift in the 1950s toward more variety and more horsepower. Top speeds increased over the years as the number of gears increased from three on earlier models to as many as six on the Fordson Major. Weight tended to go up with horsepower. However, the weight to horsepower ratio dropped from 149 to 126 lbs. per horsepower at the belt. Similarly, the ratio of drawbar to brake horsepower increased from roughly 51 percent on the original Fordson to 71 percent on the Fordson Major. Where early models used kerosene or distillate, the 1930s saw a trend toward gasoline and finally some versions of the Fordson Major using diesel.

International Harvester Corporation

International Harvester the Company

International Harvester represents yet another company originating with agricultural implements pioneers and traveling through acquisitions, merger, and additional acquisitions until being acquired by a conglomerate. In the process, the company progressed from pioneers, to a family controlled business, to professional managers, to conglomerate management. An early participant in the development of the gasoline traction engine, but not steam, the company achieved a dominant position in the industry by the end of the 1920s, despite the merger mania practiced by most of their competition. This domination lasted until the 1980s when the company suffered from the soaring value of the dollar, labor problems, and the agricultural downturn (Rasmussen 1993). Agreement was reached in 1985 to sell the agricultural equipment assets to Tenneco, Inc. of Houston, TX (Pripps and Morland 1998).

What became known as International Harvester originated with two bitter rivals in the harvester business, Cyrus Hall McCormick, founder of McCormick Harvesting Machine Company of Chicago, IL and William Deering, founder of Deering Harvester Company of Shabbona, IL. Cyrus McCormick died in 1884 but before that the two founders discussed a potential merger. Pride prevented the consummation of the deal. By 1890 with William Deering nearing retirement, he led a group consisting of McCormick (by now it was C. H. McCormick, Jr.), Deering and eighteen smaller rivals in an attempt to form the American Harvester Company. The deal fell through when the smaller companies attempted to overprice their assets in an attempt to gain a larger share of the proposed company. Things continued as they were until the 1896 and 1897 recession. Mergers became common, and again McCormick and Deering started serious negotiations. The talks appeared doomed until one George W. Perkins, a J. P. Morgan partner and advisor to the McCormicks, proposed establishing a ten-year stock trust. The trust would hold the stock of both companies with McCormick, Charles Deering

(William's son), and Perkins as trustees. On July 28, 1902 the deal was struck and thus was formed the International Harvester Company (Pripps and Morland 1998; Klancher 1995)

Neither of the founding companies, however, had been oblivious to the emerging potential of the international combustion engine. Deering made its first engine in 1891, a 2-cylinder, 6 hp device. McCormick produced its own engine in 1897. After the merger, International Harvester became one of the first long-line companies to produce a tractor. The initial unit was faulty. By 1910, however, International Harvester had overtaken Hart & Parr Company as the leader in tractor manufacture. These units were in the mold of the steam traction engine except that propulsion was provided by an internal combustion engine. Their average weight to horsepower ratio averaged about 500 lbs. per belt horsepower. One line was sold under the Mogul name through the McCormick network of dealers while the Deering network marketed essentially the same equipment branded as the Titan. In an attempt to attract small farmers to replace their horses with a tractor, Bull Tractor Company introduced a small tractor in 1913 with a price tag in the $400 range. The unit had many faults and disappeared quickly, but not before presaging the future. The stage was set for Henry Ford and his Fordson in 1918 (Pripps and Morland 1998).

With the introduction of the Fordson, International Harvester was forced to counterattack, and they did so with the release in 1923 of the McCormick-Deering 10-20. This unit was a scaled down version of the 15-30. It was small, reliable, and featured great maneuverability (Klancher 1995). However, International-Harvester had begun research on a new series as early as 1916. The final design was a composite of the light and heavy tractor lines, weighing in at approximately 3,200 lbs. In 1923 the new line was officially designated as the *"Farmall."* That same year, 25 prototype units were placed in field trials. This number increased to 200 units in 1924, and 250 in 1925. Part of this extended development period was because of manufacturing capacity devoted to the 10-20, and partly because of management reticence to devote resources to the dramatically different Farmall. Despite this, popular wisdom credits the Farmall with driving the Fordson out of the market, while the production of 200,000 10-20s probably had a greater impact. The 10-20s actually outsold the Farmall until 1930, well after the closure of the Fordson assembly lines in 1928. As with most successful new products, the Farmall was actually an amalgam of previously tested ideas. The Bull was small, the Wallis Cub was three-wheeled and the Moline Universal was tall and appeared spindly (all the better for clearance over row crops). All these features were incorporated into the Farmall. The Farmall became the dominant tractor from its inception, into the 1930s and until the 1980s – a run of 50 years. Table 19 shows the dominant position International-Harvester achieved with the Farmall. The second Farmall series became designated the *"F,"* while the original version posthumously became the *"Regular."* The F series and subsequent letter series carried International-Harvester through the Great Depression. In 1954 the hundreds series was introduced, but was little changed from the letter series. The hundred series continued through to the 1980s when the downhill slide to acquisition began.

During the period from the merger forming International-Harvester until its acquisition by Tenneco in 1985, there was virtually no change in corporate structure (Figure 35). A few implement manufacturers were acquired to extend the corporate products lines. Things were tough for International-Harvester in the 1970s and 1980s. Harvester had failed to reinvest in plant maintenance and cost-reduction technology. Interest rates were high and money sources scarce, thus precluding farmers from borrowing for equipment upgrades (including tractors). In the 1980s, the United Auto Workers Union struck Harvester for six months. All these factors combined to strike a deathblow. After a period of negotiations, Tenneco, Inc. of Houston, TX acquired the agricultural implements components of Harvester, and merged these operations with the previously acquired J. I. Case Company (Pripps and Morland 1998).

International Harvester Models

Early tractor models from International Harvester were sold first under the Mogul and Titan logos as they were distributed through the as-yet unconsolidated McCormick and the Deering dealerships. These products were of the behemoth variety. In fact, the 1913 45 hp Titan weighed in at 21,000 lbs., and bore much more resemblance to a switching steam locomotive than to a modern day tractor. When it became obvious that a competitor for the Fordson was necessary, a model 15/30 was marketed as the International (Table 40). A stripped down version, the 10-20, became the first of the Farmall line. After the introduction of the Farmall, International Harvester continued both market lines though in a non-competitive fashion, not unlike Ford Motor Company's Ford, Mercury, and Lincoln automobile lines. The dominant line, and the one that propelled International Harvester to the top of the market (Table 19) was the Farmall.

Judging from the Farmall's popularity, the trends observed in Farmall models over the years were probably trend setting for the competition. With the notable exception of the Cub, introduced in 1947 as a precursor to today's garden tractors (9.23 Bhp), Farmall models trended toward more horsepower, particularly after World War II. Weight to horsepower ratios trended downward. The 1931 F-30 weighed 183 lbs. per belt horsepower, while the Super MD introduced in 1952 had this ratio down to 128. This downward trend was accomplished by holding weights somewhat stable while increasing horsepower. The fuel of choice trended from kerosene to distillate to gasoline and finally diesel. High gear speeds, running consistently at 3.75 mph during the mid-30s, had ballooned to as high as 16.75 mph by the mid-50s. The introduction of pneumatic tires had the desired effect of increasing drawbar horsepower to belt horsepower from the Regular's 63 percent to the H's 81 percent in the time span from 1925 to 1939.

Commensurate with Harvester's truck line being marketed as International, the tractor line under the same name tended to be more industrial with the TD line of diesel crawlers. An exception was the early years, particularly marked by the introduction of the PTO on the 8-16 in 1920. All the trends of other crawler models were present in the International models. Weights, horsepowers, fuels, and number of gears mirrored the trends described for Caterpillar.

An evolutionary step, rating up there with introduction of pneumatic tires and the 3-point hitch, was that of the power take-off or PTO. Originally conceived by a French engineer and adopted for the I-H 8-16, the PTO allowed the tractor to power trailed implements. The PTO transformed many farm chores from multi-person to single operator tasks performed from the seat of the tractor. The 8-16, because of its size, immediately became popular for operating a binder. Using tractor power it was now possible to cut and bundle a crop exclusively using tractor power (Halberstadt 2000). This innovation was a significant factor in jump-starting the Farmall to its position of prominence.

Massey-Harris-Ferguson Company

Massey-Harris-Ferguson the Company

Massey-Harris-Ferguson's historical development bears some parallels with International Harvester. Daniel Massey and Alanson Harris started their companies in 1847 and 1857 respectively. Both were in the agricultural implements business. Massey specialized in implement repair and making implements for the local farmers. Harris tended toward manufacturing harvesting equipment as mowers and reapers. Both companies were located in Ontario. Their operations remained Canadian oriented for many years, then expanded into a robust export business. The decision to merge the companies came in 1891, and thus was born Massey-Harris (Figure 36) (Massey Ferguson 1999).

Massey-Harris was slow to move into powered farm equipment despite the tremendous amount of activity which had been generated following the introduction of the steam traction engine. Deyo-Macey was purchased in 1910, but this company specialized in manufacture of gasoline engines (Figure 36). World War I provided the impetus for Massey-Harris to complement their implements lines with a tractor. The first move in this direction was to arrange a marketing agreement with Bull Tractor Company. Massey-Harris was to market the *"Big Bull"* tractor, a 10-25 hp monster built along the lines of the original gasoline traction engines. The deal was struck in 1917 and in 1918

Henry Ford introduced the Fordson. The deal fell apart, and Massey-Harris was forced to look elsewhere. The next attempt at entry into the tractor business was with Parrett Tractor Company of Chicago, IL. Massey-Harris would manufacture Parrett tractors at their facilities in Canada and market them under the Massey-Harris name. The deal came together in 1918 and production was initiated in 1919. Three models were produced, the MH 1, 2, and 3. This line was rated at 12-25, 12-25, and 15-28 hp respectively. By 1923 these units were no longer competitive, sales declined, manufacture was stopped, and even the Parrett Company itself went out of business (Williams 1992a).

The agricultural depression of the 1920s dampened interest in the tractor business following the Parrett Company failure, and it was not until 1928 when a third try was initiated with the purchase of the J. I. Case Plow Works. The Plow Works Company was the *"other"* Case company operating in concert and then in competition with the Threshing Machine company. Massey-Harris paid $1.3 million for the company plus assumption of $1.1 in debt. They recouped $700,000 by selling exclusive use of the Case name back to the Threshing Machine company. The acquisition had appeal because of Case's purchase in 1919 of the Wallis Tractor Company in 1919. Wallis was producing a well-respected line of tractors which Massey-Harris immediately began marketing under their own name. Hence the Wallis 20-30 and 12-20 immediately became the MH 20-30 and 12-20. The timing was excellent since Ford had bowed out of the U.S. market, moving all Fordson manufacture to Cork, Ireland and Dagenham, England.

Prior to the Plow Works acquisition, Massey-Harris engineers had been working on an in-house design. This work had commenced in 1926, and by 1930 the General Purpose was ready for market. This was a row crop tractor with 30 inches of clearance under the axles and adjustable wheel settings from 48 to 72 inches. It was also a 4-wheel drive machine. Six years of marketing and a major update all proved disappointing. Other Massey-Harris designed models were introduced in the late 1930s during one of the worst ever markets for tractors. In an attempt to attract the small tractor market, Massey-Harris agreed to distribute the Cleveland Tractor Company General. This was, of course, before the acquisition of Cleveland Tractor by Oliver Farm Equipment Company in 1944. Again the deal did not provide positive results, and the project was dropped (Williams 1992a; Massey-Ferguson 1999).

As with all the manufacturers, World War II stopped development and most production. Following the war a series of models were introduced covering all the various size markets. With the introduction of the Ford 9N utilizing the Ferguson system it became obvious that Massey-Harris had nothing, nor could they develop a counter to the popular model. Meanwhile, the Handshake Agreement between Harry Ferguson and Henry Ford collapsed after Henry Ford II took over Ford Motor Company in 1946 and Henry Ford died in 1947. Ferguson started his own firm and sued Ford. The Ferguson tractor was a successful unit bearing a striking resemblance to the Ford 9N (also known as the Ford-Ferguson). Eventually the Ferguson tractors displaced the Fords at the top of their market. But Harry Ferguson was getting older and was tiring of the management details of running his own firm. Massey-Harris needed Ferguson, and Ferguson was a receptive bride. Ferguson was purchased for $16 million in 1953. The name was changed to Massey-Harris-Ferguson and was known simply as Massey-Ferguson (Massey-Ferguson 1999; Williams 1992a). The marriage had many difficulties, but lasted.

In the ensuing years the Massey-Harris and Ferguson lines were merged, and new models produced to address the widening market for tractors of varying horsepower. The company continued to expand, and purchased several additional firms including Perkins Diesel Engine Company (1959) whose engines Massey-Ferguson had been using in some models. Also in 1959 the Standard Motor Company was acquired. This was, of course, the company which had formerly made Ferguson tractors in the U.K. Massey-Ferguson grew to be the largest tractor manufacturer in the world for a time. However, in 1993 Massey-Ferguson sold distribution rights to the new AGCO, and in 1994 the remainder of the company was acquired by AGCO (AGCO 2000).

Thus the company went from pioneering blacksmiths to merged companies. Companies were acquired. Licensing and marketing agreements were struck. A final acquisition propelled the company to the top of the tractor market. Finally all assets were sold to the new international conglomerate.

Massey-Harris-Ferguson Models

As noted in Figure 36, Massey-Harris did not, itself, get into the manufacture of tractors until after the acquisition of J. I. Case Plow Works in 1928 along with their Wallis line of tractors. The old Wallis models were immediately relabeled as Massey-Harris. For the next 25 years Massey-Harris was at the lower end of the major seven manufacturers (Table 19). However, the 1953 acquisition of the Ferguson Company and the Ferguson line of tractors, and Harry Ferguson's technology patents, started Massey-Ferguson on its upward trend. This ascendance took place after the 1954 cutoff, therefore, Table 41 only includes the period of the Massey-Harris tractors. During this period Massey-Harris tended to concentrate on mid-range tractors, mostly presenting models in the 20s and 30s horsepower range. These were almost exclusively 4-cylinder engines, with fuels trending from distillate and gasoline to gasoline and diesel. High gear top speeds moved upward from 4 mph to as high as 17.85. These tractors placed Massey-Harris firmly with 1 percent of the market as of 1935. The technology over at Ferguson, however, was quite different. The Ferguson tractors had been the inspiration for Ford's 9 and 2Ns, and more recently the 8N. All the models submitted to the Nebraska Testing Laboratory between 1951 and 1957 were gasoline powered. Horsepower ratings were in a narrow range from 24 to 31 Bhp. The latter two models went from four to six forward speeds, presaging the move to more gears for more flexibility. The most striking technology, however, related to the weight to horsepower ratios. These ranged from 114 lbs. per belt horsepower for the TE-20 tested in 1948, to an eye-catching 110 for the 40 tested in 1956 (Table 37). For legal reasons this model was still labeled as Ferguson despite the 1953 merger, but identical, save for colors, to the Massey-Harris 50. The two tractors were even tested at Nebraska at the same time (test numbers 595 and 596).

Minneapolis-Moline Company

Minneapolis-Moline the Company

Minneapolis-Moline is yet another example of a venerable agricultural implements company whose roots trace back to 1852 in the form of the Candee and Swan Company of Moline, IL (Figure 37). Many acquisitions later the company with direct lineage to Candee and Swan became Moline Implement Company. This company along with two others all found themselves caught in the pressure of the industry for expansion, demand that they keep up with rapidly changing technology, and the agricultural depression of the early 1920s. Merger was the route taken in 1929. Three companies merged to form Minneapolis-Moline Power Implement Company of Moline, IL. After an additional acquisition, Minneapolis-Moline was itself acquired and became part of triumvirate forming White Farm Equipment Company (WFE) of Oak Brook, IL.

Prior to 1929, the three participants in the merger had each been involved in acquisition and transmogrification as indicated in Figure 37. By 1949 the company name had evolved to Minneapolis-Moline Company. Following a final acquisition in 1951, the company was sold to White Farm Equipment Company as one of the three acquisitions leading to the forming of the WFE conglomerate. Here pioneers were succeeded by companies who merged, and were ultimately acquired by a conglomerate.

The first company of the three involved in the 1929 merger was the descendent of Moline Plow Company of Moline, IL which traced its own origins back to 1852 when the company of Candee & Swan was formed. It became Moline Plow Company in 1870. The company remained in the agricultural implements business until 1915 when it purchased Universal Tractor Company of Columbus, OH and began manufacture and marketing of the Universal line of tractors. Universal had, in turn been in the tractor business for some time, having entered a 20 Bhp unit in the Winnipeg Industrial Exhibition of 1908 (Sayers 1996).

The second company involved in the merger was Minneapolis Threshing Machine Company (MTM) formed in 1887 from the previous Fond du Lac Threshing Machine Company. MTM began manufacturing steam traction engines in 1888. In 1910 MTM began marketing the Universal tractor, and in 1920 introduced the Minneapolis tractor.

Between 1920 and 1929, MTM submitted seven models for Nebraska tests. At the time of the merger, the 17-30 (Types A and B), and the 39-57 continued in sales until stocks were exhausted.

The third member of the triad was Minneapolis Steel & Machinery Company (MS&M) of Minneapolis, MN. Organized in 1902, the company initially fabricated steel sections for bridges. Shortly thereafter, the company began manufacturing a line of stationary steam engines of the Corliss design. By 1910, MS&M entered the gasoline traction engine market with its Twin City line.

The merger of the three companies resulted in a single, viable entity. The formation of the new company on May 16, 1929 (the same year that Oliver Farm Equipment was created through merger) fortuitously preceded the October stock market crash by five months. All three had been or were suffering from cash shortages. Without the merger it could be argued that none of the participants would have survived. The merger provided an infusion of capital for newer and more efficient products, while allowing obsolete and duplicative models to be phased out.

The new company started with two tractor lines. The Minneapolis (Universal) line was phased out as stocks were depleted. Twin City tractors continued to be manufactured until 1938, though starting in the early 1930s an interim logo of Minneapolis-Twin City was used. After 1938 only the Minneapolis-Moline logo appeared on company products, though as late as 1940 Nebraska tests 341 and 352 featured tractors listed as M-M Twin City RTU and M-M Twin City ZTU (Wendel and Morland 1990).

From 1929 until 1949 the merged companies operated as Minneapolis-Moline Power Implement Company. Prior to World War II, the new company struggled through the merger and the Great Depression. After Pearl Harbor virtually every manufacturer shifted to some form of war production. The war itself and the technology spawned therefrom pushed mechanized farming forward immeasurably. While power lifts were being introduced prior to the war (see the Ferguson system), the progress made in hydraulics during the war allowed this technology to be introduced not only on the tractor, but to agricultural equipment in general. Enhanced steel alloys resulting from wartime research were soon applied to tractors, allowing lighter equipment and reduced manufacturing costs.

Notably, during this period from 1929 until 1949, Minneapolis-Moline had no changes in corporate structure nor were any mergers or acquisitions completed (Sayers 1996). In 1949 the company changed its name to Minneapolis-Moline Company. The B. F. Avery Company of Louisville, KY was acquired in 1951. The 1950s saw boom and decline. In 1954 the company had a $24 million backlog in defense contracts, but with tumbling sales suffered a $426,000 loss. The loss was attributed to inflexible high operating costs and declining farm prices. Additionally, foreign sales were off, and a failed attempt to penetrate the Turkish market drained company resources. Saving the company at this time was a popular line of in-place stationary engines. White Motor Company made overtures to purchase Minneapolis-Moline starting in 1955. After political infighting regarding Board of Directors membership, the takeover was accomplished on January 23, 1963 for a mere $21 million. Minneapolis-Moline became the third of the three acquisitions ultimately becoming the nucleus of White Farm

Equipment Company with corporate headquarters in Oak Brook, IL (Sayers 1996; Wendel and Morland 1990). Table 21 shows some Minneapolis-Moline firsts achieved during its history and that of its predecessors.

TABLE 21
SOME EARLY MINNEAPOLIS-MOLINE FIRSTS

Year	Event
1870	First commercially successful grain drill
1900	First commercially successful cylinder corn sheller.
1914	Started manufacture of "Bull" tractors – the first mass production of low-priced tractors.
1915	Moline Universal tractor, first all-purpose tractor with a complete line of tractor-attached machines built especially for it
1918	Famous Twin City 12-20
	First standard design tractor with enclosed gears
1923	First all-steel threshers – Twin City
1925	Lowest built manure spreader introduced by Moline
1928	Famous Moline two-way tractor gang plow for irrigated and hilly fields – "Tumblebug"
1929	Original Wheatland disc plow with 26 in discs
1934	M-M 12 ft harvester – the original lightweight, big capacity combine weighing nearly a ton less than previous combines of this type.
1935	M-M sold the first tractor with high-compression head using regular high-octane gasoline.
1937	First Visionlined tractor, the "Z," featuring an entirely new engine with 140 fewer parts than conventional tractor engines
1938	Comfortractor, the "UDLX," first tractor equipped with cab and other comfort features as regular equipment
1940	M-M introduced the first military vehicle called the "jeep," a farm tractor conceived to serve defense purposes
1941	M-M introduced first tractor with factory-installed LP gas-burning equipment

(Sayers 1996, 92)

Minneapolis-Moline, Minneapolis Threshing Machine, B. F. Avery, and Twin City Models

Prior to Minneapolis-Moline's acquisition by White Farm Equipment in 1963, tractors manufactured and marketed under four different names ultimately funneled into the Minneapolis-Moline organization.

The earliest manufacturer was the Twin Cities organization of Minneapolis. The Twin City logo and one of the early Twin City tractors are included in Figure 13. Note

(Minneapolis-Moline 2002)

Figure 13 – Twin City logo and an early product – probably a Model 40, circa 1910.

the large corrugated metal canopy – a carryover from the steam traction days. The unit is equipped with steel wheels with lugs – a standard configuration until the introduction of pneumatic tires by Allis-Chalmers in 1932. Also note the drive wheel forward of the rear wheel – used as a belt takeoff for threshing. The model 40 weighed in at 25,500 lbs.

To supplement their own line, in 1913 Minnesota Steel & Machinery contracted with Bull to produce 4,200 tractors, thus maximizing the throughput on their production lines and profits as well. Between 1913 and the merger, MS&M introduced 12 models, the last six of which were submitted for Nebraska tests. The 40-65 was in the big-tractor mold, weighing in at 25,500 (Table 46). Subsequent models ranging from 1920 until 1930 were of the newer, general purpose type with horsepower ranges from 27 Bhp (12-

20 in 1920) to 49 (AT, 27-44 in 1926). All these models were 4-cylinder, kerosene powered, with 2 or 3 forward speed units.

Minneapolis Threshing Machine Company marketed a series of tractors branded simply as Minneapolis. Seven such models were submitted for testing at the Nebraska Testing Laboratory between 1920 and 1929. With the exception of the 35-70 tested in 1920, the models were of the newer design, ranging from 26 to 64 Bhp. All were 4-cyninder and had two forward speeds. Kerosene was the standard source of fuel with the exception of the last model, the 39-57, which featured gasoline. After the merger, the Universal tractor inventory was sold off and the Twin City logo retained for a short time.

Table 31 shows B. F. Avery models submitted for testing between 1920 and 1923. These models mirrored those submitted by Universal of the same period. They were, of course, competitors at the time. With the exception of the 45-65 tested in 1920 (a 22,000 monster throwback to before the general-purpose revolution), all were mid-range from 24 to 44.5 Bhp (the 12-20 in the former case, and the 18-36 in the latter case, both submitted in 1920). Kerosene was the fuel of choice until the latter part of the period when two gasoline models were introduced. Drawbar to brake horsepower ratios ranged from a very respectable 72 percent (12-20 in 1920), to a modest 55 percent for the 12-25 in 1921. No tractors were submitted for testing between 1923 and the acquisition of the company by then Minneapolis-Moline Company in 1951.

Finally, after the Twin City logo was phased out, 12 models were submitted under the Minneapolis-Moline logo for testing between 1931 and 1954. Ten of these models were gasoline powered (one was fuel, the other was LPG) (Table 42).

During the 1930s Minneapolis-Moline introduced several revolutionary concepts. Most notable, perhaps, was the Universal de Luxe or UDLX (Table 21). This was the first tractor with a completely enclosed cab, and was marketed as being able to double as a tractor during the day, and as a family vehicle in the evening. Ahead of its time, the UDLX received less of a reception than merited because of the widespread perception that only *"sissies"* needed the comfort of an enclosed cab. Other firsts for Minneapolis-Moline during the 1930s included a 5-speed transmission and the first high compression engine (5.25:1) for tractor use (Wendel and Morland 1990; Sayers 1996).

Oliver Farm Equipment Company

Oliver the Company

Oliver Farm Equipment Company came into being as a result of merger and ceased to exist as a result of acquisition. While in independent operation from 1929 until 1960, the company produced many popular lines of tractors and crawlers, and was at the forefront of significant innovations. Figure 38 contains a genealogy of the company.

The company was formed in 1929 through the merger of three venerable agricultural implement companies: Oliver Chilled Plow Company, America Seeding Company, Nichols & Shepard Thrashing Machine Company, and the tractor pioneering company of Hart & Parr (Figure 34). Soon thereafter, McKenzie Potato Machinery was added to form a broad-range agricultural equipment company (Morrill and Hackett 1996). Fifteen years would pass before there was another major acquisition. The Cleveland Tractor Corporation of Cleveland, OH, manufacturer of Cletrac crawlers was added in 1944 (Letourneau 1993; Sanders 1996).

Oliver's initial tractor manufacturing operations came entirely from the former Hart & Parr part of the merger. Founded by Charles W. Hart and Charles H. Parr, the Hart & Parr company is credited with two historic milestones. Having started manufacture of stationary gasoline/kerosene engines in 1896 and tractor production in 1901-1902, they discontinued engine production in 1905, thus becoming the first company to devote itself solely to the manufacture of gasoline traction engines (Gay 1997). And, in 1907, the advertising manager, W. H. Williams, started using the word *"tractor"* to replace the more cumbersome *"gasoline traction engine."* The word itself resulted from the contraction of two words: *trac* (tion) and (mo) *tor* (Sayers 1996). Hart & Parr's first tractor, simply called Hart-Parr No. 1, was a 30 horsepower (17/30) stationary engine mounted on a pipe frame chassis (Gay 1997). Construction commenced in 1901 and was completed in 1902. Hart & Parr was proud of its equipment, and used performance records in their advertising. They noted that in 1925 seven of the first 15 units produced were still in use, and six remained in use in 1928 (Gay 1997). As with most of the pioneering companies, the initial models were huge in comparison with those produced later. The Model 20-44 produced from 1911-1914 was an incredible 52,000 lbs. By the time of the merger, models such as the 12-24E, produced from 1924-1926 weighed a mere 4,675 lbs. while rated as 16.99/26.97 in Nebraska Test No. 107. No diesel-powered models were produced. Gasoline, kerosene and distillate were used on all Hart & Parr models through the history of the firm (Table 39). By the end of 1929, following the merger and after reorganization was complete, revenues placed it in a tie for third place with J. I. Case in the farm implement industry, behind only International Harvester and Deere & Company (Gay 1997) as indicated in Table 19.

In 1944, during the later years of World War II, Oliver acquired the Cleveland Tractor Corporation of Cleveland, OH, manufacturer of the *"Cletrac"* line of crawler tractors. This company traced its origins back to a founding in 1911 when the brothers Rollin H. and Clarence White formed the Cleveland Motor Plow Company. The company was incorporated in 1917 as Cleveland Tractor Corporation. From the start the company's product was a crawler dubbed the *"Motor Plow,"* a competitor to Caterpillar. Following the acquisition by Oliver in 1944, the name Cleveland and the trademarked Cletrac name were dropped as Oliver re-branded these products as Oliver.

In a dramatic move into the tractor industry, White Motor Company made Oliver the first of four companies to be acquired in the 1960-1966 time frame. Cockshutt Farm Equipment Company was acquired in 1962, Minneapolis-Moline was acquired in 1963, and the Hercules Engine Division of Hupp Corporation was acquired in 1966. In 1969 this set of acquired companies was spun off to form White Farm Equipment Company (Sanders 1996; Gay 1997). While the Hart & Parr name disappeared in 1929 and the Oliver name disappeared in 1960, significant milestones have been attributed to these two venerable names in tractor history (Table 22).

Oliver Models

The original tractor line feeding into Oliver was that of the Hart & Parr Company. The first company to concentrate solely on tractors, the original No.1 was manufactured in 1902 with a production run of one. Table 39 is segregated into Old and New Hart &

TABLE 22
HART & PARR AND OLIVER CONTRIBUTIONS
TO TRACTOR DEVELOPMENT

Hart & Parr Contributions.
Replacement of steam engine power for agriculture
Successful internal combustion tractor mass production
First tractor production plant
Kerosene-burning engine
Oil-cooled engine
Valve-in-head engine
Independent power take-off (PTO)
Force-fed lubrication in tractor engines (as opposed to splash)
Gave the word "tractor" to the industry
First foreign tractor business (Russia)
Oliver Contributions:
Tricycle row crop tractor
Economical, practical diesel tractor
Practical independent power take-off
Mass production of six-cylinder engines
Tip Toe wheels
Electrical control of hydraulics
Equalizer brake pedals
Double disk brakes on tractors
Low-pressure engine lubrication system
Aluminized steel mufflers
Tilt and telescoping steering wheel
Four-wheel drive with terra tires
Wheel guard fuel tanks
Certified horsepower
Two-point hitch and lower link draft control
Cast-iron grille for row crop stability
Ridemaster seat
Electric lights
Bale thrower
Throw-away Raydex shares

(Morrill and Hackett 1996, 20)

Parr sections to distinguish the before and after Fordson models. While little information was available on the older models, horsepower and weight figures indicate that these units were of the behemoth variety. However, Hart & Parr reacted quickly to the

Fordson. Their first model submitted for testing at Nebraska was the 15-30C (test number 26 in 1920). These are the models listed in Table 39 as new Hart & Parr. The appearance of this model was along the lines established by the Fordson, though a bit more powerful. This unit produced 31.37 horsepower at the belt and 15.56 at the drawbar. The drawbar to belt horsepower ratio was a rather poor 50 percent and the weight to horsepower ratio came to 173 lbs. per belt horsepower. Neither ratio was very impressive, but both were routine for these early tests. The last four models submitted to Nebraska carried the Hart & Parr logo, even though they were completed after the Oliver merger.

From 1930 until the end of the examination period, Oliver submitted 31 models for testing (Table 45). Nothing stands out as bucking any of the trends noted for all the other competitive tractors during the 1930 to 1954 time frame. With the exception of the RC 60 with a test belt rating in the teens, two models with horsepower ratings in the 40s, and the DD introduced in 1949 at 73.3 horsepower, the market niche sought out by Oliver was the general purpose market in the 20s and 30s range. Fuels trended, as usual, from kerosene to gasoline to diesel. The number of forward gears trended upward as did top speeds. Oliver did start producing 6-cylinder models earlier than most competitors and continued to produce a significant number of these machines. Drawbar to belt horsepower ratios were rather good, ranging from the upper 60s to mid 80s percentage ranges. Weight to belt horsepower ratios seemed to vary considerably. The 80 Standard HC tested in 1940 had a 178 lbs. per belt horsepower ratio. This contrasted with the 117 lbs. per belt horsepower attained with the Standard 66 HC tested in 1949. Of course the Cletrac models re-branded as Oliver came in much heavier. The DD tested in 1950 had a

211 lbs. per belt horsepower ratio. However, the lightweight, low powered HG of 1949, weighing only 4,183 lbs., had only a 117 lbs. per belt horsepower ratio.

White Farm Equipment Company

White Motor Company is representative of companies entering the agricultural tractor manufacturing business through acquisition and subsequently being incorporated into a conglomerate itself. Highlights of the company's genealogy are shown in Figure 39. After successive ownership by two companies and a merger of operations, what was then known as White-New Idea was acquired by the newly formed AGCO.

Prior to 1960 White Motor Company had nothing to do with agricultural implements or agricultural tractors. Then, as now, the company was noted for its line of tractors for 18-wheel road use. Starting in1960, however, and extending until 1981, White became a player in agricultural tractor manufacture. First, between 1960 and 1963, the company acquired three tractor companies: Oliver Farm Equipment Company, Cochshutt Farm Equipment Company, Ltd, and Minneapolis-Moline Company. In 1966 they added the Hercules Engine Division of Hupp Corporation and formed the White Farm Equipment Company as a wholly owned subsidiary. In 1969 the three tractor companies were reassembled into White Farm Equipment Company. It was at this time that the three previously independent tractor companies lost their corporate identities (Figure 39).

In 1981 Texas Investment Corporation (TIC) of Dallas, TX purchased the White Farm Equipment Company, subsequently operating the company as WFE. WFE filed for bankruptcy in 1985, and Allied Products Corporation of Chicago, IL purchased portions of WFE including the old tractor manufacturing works at Charles City, IA (originally built by Hart & Parr), and all the tooling machinery. In 1987 Allied merged the WFE operations with its New Idea companies to form White-New Idea (Sanders 1996; Gay 1997). It was this entity that AGCO of Duluth, GA purchased in 1993 to form the backbone of their agricultural implements and tractor operations. Today AGCO still retains the White-New Idea name for portions of their tractor products line as White Tractors, White Planters, and New Idea for various implements as round balers, disc mowers, bar rakes, and planters (AGCO 2001).

Summary of Development of the Tractor Industry

Development leading to diffusion proceeded along two paths. First was the maturation of the industry itself as it progressed from pioneers in blacksmith shops to multi-billion dollar, international conglomerates. Second was the maturation of the tractor as it progressed from a crude, sometimes dangerous, difficult to operate and maintain, limited use piece of equipment to a general purpose, indispensable part of modern day agribusiness.

Feedback from the farmers to the manufacturers played a key role in the progression of both. Once motive power became available in the field, the farmers recognized the shortcomings of the current equipment and demanded (both verbally and through their buying choices) changes and enhancements to make the tractor ever more functional. Cross industry synergy helped the manufacturers to address these demands by the farmers, but the speed of development and the demand for product forced the smaller manufacturers out of business and those better equipped to survive frequently resorted to mergers and acquisitions. Once the feedback loops were in place and flowing, the process essentially fed on itself.

Table 23 shows the trends in tractor purchase as the country emerged from the Great Depression, and prior to the interruptions caused by World War II. The total number of tractors sold in 1937 and 1940 were essentially identical. However, row crop tractors increased as a percent of the total from 85 to 95 percent. At the same time, the number of row crop tractors with less than 30 horsepower declined from 95 percent to

TABLE 23
TRENDS IN U.S. WHEELED TRACTOR SALES, 1937-1940

Year	Wheel Tractors Sold (Total)	Row Crop Tractors Sold (Total)	Row Crop Tractors as % of Wheel Tractors	Row Crop Tractors Sold Under 30 Bhp	As % of GP Tractors	Row Crop Tractors Sold Over 30+ Bhp	As % of GP Tractors
1937	216,169	183,656	84.9	173,659	94 6	9,997	5 4
1938	141,593	127,076	89 7	116,381	91.5	10,625	8 5
1939	157,497	147,206	93.4	140,281	95 2	6,925	4 8
1940	215,673	205,489	95.3	185,006	90 1	20,843	9 9

(Letourneau 1993, 97)

90 percent as the demand for more horsepower generally went up. This trend presaged the demand for horsepower so notable in the 1940s and 1950s after World War II restrictions were removed.

To summarize the overall process, Table 24 shows the major trends and developments in the industry and the equipment as it progressed to the point of replacing the horse as the source of motive power in the field.

Thus, the tractor industry matured and was transformed by mergers, acquisitions, departures from the market and world events. The tractor itself matured as a result of demands by the adopters, the competitive nature of the market, and world events. The primary vehicle for effecting these changes was the feedback loop from the diffusion process and its consequences.

TABLE 24
CHRONOLOGY OF TRACTOR DEVELOPMENT EVENTS

Period	Event
1880 to 1924	Steam traction engines appear on large prairie landholdings to supplement horses in the massive tasks of breaking up the plains for farming, subsequent plowing, and threshing
	Steam traction engines are behemoths frequently weighing 10 to 15 and even 20 tons, but capable at the end of the era of generating 100+ horsepower.
1892	As Nicolaus Otto's patents on the internal combustion engine expire, experimentation begins on replacing steam engines with internal combustion engines Charles Froelich is credited with the first such successful experiment
1902	Charles Hart and Charles Parr establish the first company devoted solely to the manufacture of gasoline traction engines
1902 to 1917	Early gasoline traction engines look and weigh approximately the same as their steam-powered predecessors. They were built not as competition with the horse, but only in competition with steam traction engines.
1918	Henry Ford introduces the Fordson. This small, light, relatively low powered vehicle intended by its size, versatility, and price appeals to the small farmer in competition with the horse
1920s	The agricultural depression causes fierce competition and price wars. Many smaller manufacturers are driven out of business and others are forced to merge
	International Harvester introduces its International 10-20 and then the Farmall in direct competition with the Fordson All manufacturers join in and the days of the behemoth tractor are over.
1920s and 30s	Horsepower goes up, but slowly
	Drawbar horsepower to belt horsepower ratios go up while weight to belt horsepower goes down
	Number of gears goes up and potential speeds go up as well
1920s to 50s	Fuels transition from distillate to kerosene to gasoline to diesel.
1920	The PTO is introduced.
1932	Pneumatic tires are introduced and rapidly take over the market.
1939	Henry Ford introduces the Ferguson system, hydraulically powered three-point hitch This becomes the internationally accepted standard for implement attachment.
1941-1945	WW II slows development due to wartime priorities, but the industry ultimately gains from wartime research in hydraulics and metallurgy
1946 to 1954	Horsepower continues to go up with power now exceeding that achieved by the steam traction engines of the 1910s.

CHAPTER 5

DIFFUSION OF THE AGRICULTURAL TRACTOR

INTRODUCTION

Rogers (1995, 10) defines diffusion as: "The process by which an *innovation* is *communicated* through certain *channels* over *time* among the members of a *social system*." Thus, his four main components of a diffusion process are the *innovation* itself, the *communication channel(s)* through which knowledge of the innovation takes place, the *temporal* aspect of the diffusion, and the *social system* in which the innovation diffuses. Any examination of the diffusion process must address all four of these aspects to fully encompass the paradigm shift to the new state of affairs following diffusion and adoption of an innovation. Rogers (1995, 11) goes further in explaining that an innovation is *"an idea, a practice, or object that is perceived as new by an individual or other unit of adoption."* This rather broad definition of the process provides for the inclusion of the spread (or adoption) of virtually any human activity whether it is merely intellectual, or incorporates a physical component as well.

Gould (1969, 1) emphasizes that the study of spatial diffusion encompasses the truism that: *"Man and his works exist in space and time."* He notes the use of the conjunction *"and"* in the definition to focus on the requirement that diffusion analysis must account for not only the spatial (latitude, longitude, and altitude) aspect of the diffusion study, but also a fourth, temporal dimension as well. Hence, Gould is particularly conscious of the consequence of space and time in defining the paradigm wherein diffusion takes place.

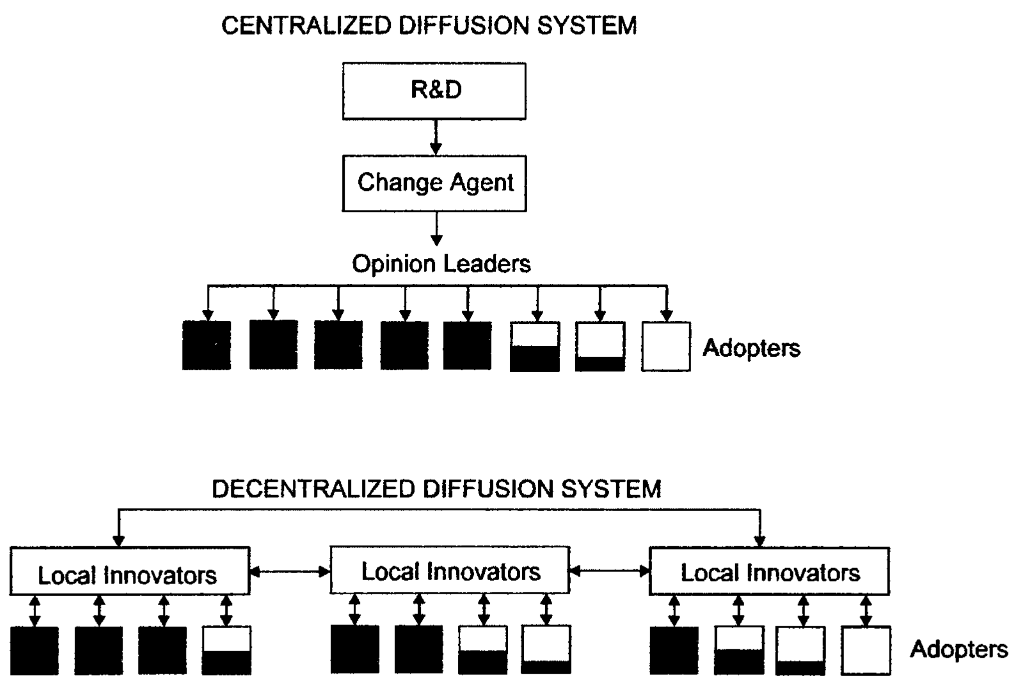
The process of diffusion does not stand alone, however. Rather, it is part of a continuum which must necessarily be preceded by the developmental process and followed by consequences (Rogers (1995, 405) uses the term "*consequences of innovations.*" In turn, the diffusion process provides feedback to the development process. Similarly, as a consequence of diffusion, feedback is provided to both the diffusion process and to the developmental process; thus completing a continuous feedback loop at every phase of the process (Figure 7).

Rogers' definition does not address the spatial component of diffusion. Hägerstrand (1967), however, views the diffusion as a spatial process. In his classic book on the subject the closest technological innovation to the tractor is a study of automobile diffusion within the area of Kinda-Ydre. This is a relatively small region of Sweden, irregularly shaped but generally 69 Km by 61.5 Km, thus encompassing some 4,000 sq. Km. His temporal framework is from 1919 to 1933. During this period he traces the automobile population's increase from 11 to 439. This micro analysis identifies car ownership by social class and maps the location of owners within the study area. This thesis, however, takes a macro view of tractor ownership. In this thesis' chapter on development it was emphasized that the location of the tractor industry itself was influenced by both the initial market (the Rural Heartland), the availability of raw material supply via the Great Lakes, and cross-industry synergy from the automotive, locomotive, and airplane manufacturing industries. The existence of the Rural Heartland as a viable early market resulted from the nature of the area (rolling prairies), the major crops (wheat and corn), and the size of farms (large relative to the northeast). Other areas, notably the Plantation South, exhibited their own diffusion characteristics and timing. These spatial aspects of the study are not emphasized as such, but underlie all of the further discussion of diffusion phenomena.

The period of interest in the diffusion of the agricultural tractor is from roughly 1880 to 1954. This period encompasses early introduction of steam traction engines (as opposed to wheel-mounted steam engines pulled by draft animals) until agricultural tractors exceeded horses on the farms of the United States (USDA 2001). This period also encompasses a significant number of exogenous forces (familial, societal, economic, and political/governmental) of such magnitude as to impact diffusion. This study of diffusion of the agricultural tractor focuses (though not exclusively) on the Rural Heartland. This is the area dominated by the corn and wheat belts, and is the area where steam traction and later gasoline traction engines found their earliest advocates and utilization.

CENTRALIZED AND DECENTRALIZED DIFFUSION SYSTEMS

Rogers (1995) presents two theories of diffusion systems: the centralized and decentralized concepts of the diffusion process. The two theoretical systems are presented pictorially in Figure 14. The centralized system is considered as the



(Rogers 1995, 367)

Figure 14. Centralized and decentralized diffusion systems.

"classical" model to the diffusion process. Here the innovation is diffused as a predefined package to a group of passive adopters. Rogers, as a rural sociologist, points out that much agricultural diffusion meets these criteria, whereby the what, where, when,

and to whom decisions of diffusion are made by a select number of technical experts at or near the top of the diffusion system. Over the years this concept has proven to be applicable, but not all-inclusive relative to differing categories of innovations. To accommodate the innovations not conveniently falling into the centralized system, a theory of decentralized diffusion has evolved. Here an innovation is conceived by a central source (an inventor, the research and development (R&D) group within a manufacturing organization), and thereafter diffuses in a horizontal fashion as local adopters exert influence on their peer groups. In this model the diffusion system is broadly shared and individual adopters may well serve as their own change agents.

It is asserted in this thesis that the diffusion process for the agricultural tractor embodies characteristics of both models, with a decided favoring of the decentralized model. In his discussion of the diffusion systems, Rogers identifies six characteristics of diffusion systems which support this conclusion. The following paragraphs address each of his six characteristics as they pertain specifically to the agricultural tractor.

The degree of centralization in decision-making and power – There was virtually no centralization in that the farmers were under n o obligation, either personally or governmentally to purchase a tractor. There was a wide sharing amongst the potential adopters of a tractor as to who would purchase a tractor and when.

Direction of diffusion - Diffusion tended to be horizontal over time. Would be purchasers evaluated their situation vis-à-vis their neighbor's, the exogenous forces affecting them personally, and other sources of information. They then made a personal decision, with the timing of a positive decision to adopt placing them in one of the adopter categories in a temporal process.

Sources of innovations – In this instance there is a mixture of centralized and decentralized characteristics. Original experimentation originated with the innovators within a manufacturing context. From the point of early diffusion, the reinvention aspects of the system became dominant.

Who decides which innovations to diffuse? – Farmers tend to be independent in their decision processes. They are non-experts in most new technology unless it is directly related to their present use of an innovation. So while the tractor originated from a central R&D organization (centralized system) within a manufacturing entity, the decision process was essentially horizontal in its implementation (decentralized system).

How important are client's needs in driving the diffusion process? – This issue is also both centralized and decentralized. Technology-pull fostered by locally perceived needs result in technology-push as the manufacturers respond to market demands.

Amount of reinvention? – Two types of reinvention exist for the tractor. From a decentralized vantage point, we note the inventiveness of the farmer in devising new uses for the tractor once purchased. From virtually exclusive use as a power source for thrashing and then plowing, to the general purpose vehicle of today, the farmer has continually reinvented its application to farm tasks. In order to accomplish this, frequently new functionality was required at various stages in the tractor's maturation process. Demands to replace the bull wheel method of powering trailing implements were met with the PTO. Demands for more efficiency between belt and drawbar horsepower were met with pneumatic tires.

In these cases demand originated with the farmer and was transmitted back to the R&D departments of the manufacturers via the feedback loops illustrated in Figure 7 – thus implying a centralized aspect to the solution of problems of enhanced functionality.

EXOGENOUS FORCES IMPACTING TRACTOR MARKET PENETRATION

Four events occurred (two concurrently) during the war and inter-war years which influenced and in some cases controlled the production (and hence sales) of agricultural tractors. First was the impact of the two great wars of the 20th century. Next was the agricultural depression of the early 1920s. Third was the Great Depression extending from 1929 until the commencement of World War II. Finally, concurrent with the Great Depression, and particularly devastating in the Rural Heartland was the drought immortalized as the Dust Bowl extending from 1931 until 1939.

The Great Wars

Geopolitically the period of interest was dominated by two world wars. From 1914 to 1918, Europe was engaged in a conflict pitting Germany, the Austro-Hungarian Empire, and the Ottoman Turks against a coalition of nations comprised most notably of England (including the Commonwealth), France, and the *"low countries"* of Belgium and the Netherlands. The United States at first remained isolated from the conflict and remained on the sidelines until 1917, when they threw in with England and France.

It is asserted here that the turmoil of World War I provided a demand for the agricultural tractor and a resulting impetus for further development and manufacture. A portion of the turmoil was caused by the ground fighting in Europe. Trench warfare is incompatible with row crops, grain fields, and pasturage. A second portion was caused by Germany's successful use of the submarine to disrupt allied shipments to England and the Continent from the United States and Canada. During the first year of the war, the German submarine fleet accounted for the sinking of approximately 300 ships comprising 600,000 deadweight tons with a loss of 6,000 lives. By September 1918 (two months before the end of the conflict), deadweight tonnage sunk (allied and neutral) had reached 15 *million tons*. The average was 400,000 tons per month (Halsey 1920). The torpedoing of allied ships at this rate meant that the allied merchant fleet was inadequate to transport American troops, essential munitions for the fighting forces, and at the same time supply the population of the British homeland with adequate food. However, the death throes of the Ottoman Empire and Turkey's entry into the conflict as an alley of Germany also played a part. Halsey (1920) notes that immediately upon entering the conflict in 1914, that Turkey blockaded the Dardanelles. This had two effects: it cut off the supply of Russian oil (a commodity of increasing importance in the mechanization of war), and it cut off the supply of Russian wheat to England and France. With Russian wheat embargoed, one of the three major wheat producers of the time (the U.S. and Canada were the other two) was unable to ship its product. At the time, Russia moved twice as much product by sea as by land (Halsey 1920). Partially as a result as a result of these combined forces, Pripps, and Morland (1994) note that by 1920, there were twice as many acres of the Great Plains under cultivation as had been in 1910.

A partial solution by the British to the food shortage was to increase domestic production. The number of draft animals available was inadequate for the task, and the British Government (in the form of the Ministry of Munitions (MOM)) contracted with Henry Ford to supply 5,000 tractors at $700 each (cost plus $50 per unit) for use in the war effort (Ford 1923; Sorensen 1956). The $700 price tag in 1917 had the same purchasing power as $9,756 in 2001 dollars (Economic History 2001). The initial units of these tractors were received in England in December 1917. Other American manufacturers supplied tractors as well. This demand, coupled with increased production of foodstuffs at home, provided a major impetus to the agricultural economy of the United States in general, and demand for tractors in particular. An interesting sidebar to the role of the agricultural tractor in World War I comes from Wik (1980). He notes that the first tanks ever used in battle were of British make at the Battle of the Somme on September 15, 1916 (49 in number). While these tanks were developed and manufactured in Great Britain, the acknowledged model for these units was the American Caterpillar farm tractor manufactured by Benjamin Holt of Stockton, CA.

The Second World War lasted longer, was played out on a greater geographic stage, and cost more lives, money and destruction of property than did World War I. Certainly this conflict has had a greater impact on the history of the 200th century than did the first. As for the agricultural tractor, there was, perhaps, less of an impact. The inter-war years were dominated by the economics of the time and the commencement of World War II closed this economic period. Tractor production, having risen steadily since 1932, crested in 1941. Wartime priorities caused production to decline until 1943, but thereafter it rose through to the close of the war in 1946. By that point production exceeded the prewar maximum (Letourneau 1993).

The Agricultural Depression

Not only did Rural Heartland plowed acreage double between 1910 and 1920, American farm income essentially doubled between 1914 and 1920 (Table 25). As European farmers recovered from the devastation of World War I more rapidly than had been anticipated, and Russian wheat again appeared on the world market, farm income plummeted to pre-1914 levels and had not recovered by 1929 when the impact of the Great Depression was felt by 1930. Incomes bottomed out in 1932 and began a slow rise lasting through to the commencement of World War II. Referring to Table 25, farm mortgage debt (slower moving than income) followed the euphoria of the agricultural boom and continued to rise monotonically from 1910 until 1923 when the agricultural depression was well established. From 1923 until 1929, mortgage debt declined and continued to decline through to the depth of the Depression in 1932. Farm mortgage foreclosures followed a trend in line with farm income and mortgage debt. From 1912 until 1917, foreclosures increased nominally from 2.4 per 1,000 farms to 3.5 in 1916. During the war and boom years this number declined to 2.8 per 1,000. Then as the agricultural depression took hold, foreclosures again started rising in 1919, continuing to 1926. From there the level remained fairly constant until 1930 when the Great Depression started taking its toll and farm foreclosures skyrocketed along with the closure of rural banks (Johnson 1973-1974). All this, of course, took its toll on the production and sale of agricultural tractors. A farmer whose income had dropped by half

TABLE 25
SELECTED RURAL FINANCIAL STATISTICS
FOR THE UNITED STATES, 1910-1933

Year	Farm Incomes for the Calendar Year (1910-1914 = 100)	Total Farm Mortgage Debt at Jan.1 (1910-1914 = 100)	Farm Mortgage Foreclosures In the 12 months Beginning March 16 (per 1,000 farms)	Year	Farm Incomes for the Calendar Year (1910-1914 = 100)	Total Farm Mortgage Debt at Jan 1 (1910-1914 = 100)	Farm Mortgage Foreclosures in the 12 months beginning March 16 (per 1,000 farms)
1910	105	81	N/A	1922	113	271	11.2
1911	86	89	N/A	1923	134	274	13 6
1912	110	100	2 4	1924	130	271	15 6
1913	94	110	2.7	1925	174	251	16 2
1914	104	119	3.1	1926	157	246	17 0
1915	106	127	3 3	1927	154	245	16.6
1916	112	133	3 5	1928	160	248	13 9
1917	199	148	3 4	1929	164	248	14 9
1918	218	166	2.8	1930	119	244	18 0
1919	230	181	3 0	1931	92	238	27.8
1920	201	214	3 8	1932	57	231	38.1
1921	92	259	6.4	1933	64	215	27 1

(Johnson 1973-1974, 176)

and whose farm was in danger of foreclosure was not likely to purchase a new tractor no matter what the economics of tractor utilization indicated.

While the agricultural depression acted overall as a barrier to diffusion, the tractor wars of the early 1920s provided a certain incentive. As farm product prices worsened in 1921, tractor sales slumped correspondingly. At the time, there were 166 companies selling some 200,000 units per year. Deere & Company had recently entered the tractor market with their purchase in 1918 of the Waterloo Gasoline Engine Company (Waterloo Boy Tractors). Deere had scheduled manufacture of forty units per day for 1921. With the downturn, Deere sold only 79 units in *the entire year*. Ford, however, was scheduled to produce 200 units per day of their Fordson F. The result of over capacity and overproduction was a price war with Ford leading the way. Ford reduced their price from $785 to $620, and finally to $395. Many of the independent manufacturers closed up shop, were acquired or merged. Even General Motors withdrew its Samson Iron Horse from the market. Ford, however, sold 35,000 units in 1921, 67,000 in 1922, and 100,000 in 1923 (Williams 1992b). The farmers profited from reduced prices, and Ford elbowed many competitors out of the market.

The Great Depression

The Great Depression commenced following the stock market crash of October 1929. Stock prices artificially inflated during the 1920s boom plummeted. The depression quickly spread throughout the world. Farm income (Table 25), indexed to 1910-1914 as 100, peaked at 230 in 1919 prior to the post World War I agricultural depression. By 1929 indexed farm income had recuperated to 164, but by 1933 farm income had plummeted to 64. At the same time farm mortgage debt having peaked at an indexed value of 274 in 1923 declined to 215 by 1933. Similarly foreclosures which had peaked at 17 per 1,000 farms in 1926 then declined up until 1929, then skyrocketed to 27.1 by 1933. Obviously, as foreclosures increased, bad mortgage debt declined.

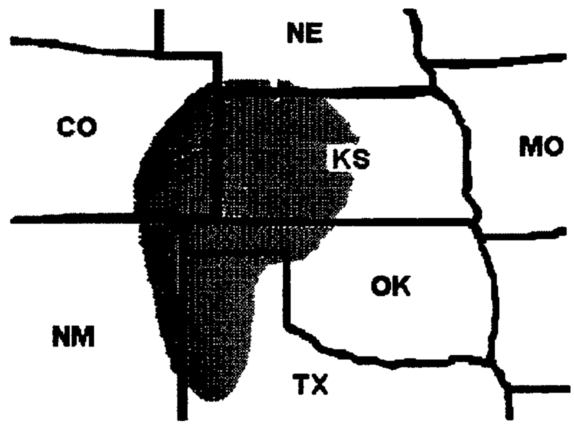
While every farmer's case and problems were unique, common threads existed. Young farmers of the 1910s who had experienced nothing but rising prices for farm products were frequently heavily in debt. Generally there was a first mortgage secured from the Federal Land Bank, an insurance company, a mortgage company or perhaps a local bank. Frequently the seller of the land would carry a second mortgage for whatever amount the prime lender was unwilling to finance. With heavy interest payments, taxes, and routine operating expenses, any interruption in current income forced the borrower into debt to secondary creditors such as the doctor, implement dealer, grocery, or feed stores. An older farmer with outright title frequently used the land as collateral to buy additional land, placing him in the same situation as the young farmer. Once the spiral commenced in the post World War I agricultural depression, many farmers were still in debt when the Great Depression struck starting in 1929 (Johnson 1973-1974).

As debt mounted and debt servicing difficulties and foreclosures increased, the government intervened in both formal and informal ways. Incorporated in the New Deal were acts creating the Commodity Credit Corporation (CCC), the Farm Credit Administration (FCA), and the Agricultural Adjustment Administration (AAA). All were aimed at restoring farm prosperity (Clarke 1991). However, even the efforts of these agencies were not sufficient. In 1933 Governor Morgenthau of the Farm Credit Administration directed the state governors to establish groups of voluntary local community leaders into farm debt adjustment committees. These committees acted in the role of quasi-binding arbiters between a farmer and his collective lenders to reach a settlement regarding debt obligations (consolidation of debts, deferments of payments, assurances of non-foreclosure), avoiding foreclosure where possible. All this served to ameliorate what was a disastrous shortfall between farm income and debt servicing.

Farm foreclosures were not evenly distributed throughout the U.S. Heavily hit were farmers in the Rural Heartland. Whereas farmers in the northeast may have had a farm in the family for generations, Rural Heartland farmers were, for the most part, first generation and hence more likely to have incurred debt for land, home and equipment. By 1933 such Rural Heartland states as North and South Dakota, Minnesota, and Montana were experiencing foreclosures at twice the rate of the U.S. as a whole (Alston 1983).

The Dust Bowl

In 1931 a severe drought hit the mid-western and southern plains. The area affected included a small portion of southwest Nebraska, the western half of Kansas, southeastern Colorado, the panhandle of Oklahoma, the far eastern portion of New Mexico and the panhandle of Texas (Figure 15). Dubbed the *Dust Bowl*, the drought was exacerbated by over-plowing and over-grazing. As the crops died, the *"black blizzards"* began. In 1932 there were fourteen such blizzards and by 1933 the number had increased to 38. By 1934 the storms had spread outside the Dust Bowl area, and eventually affected 27 states comprising 75 percent of the United States. In December of 1935, the *Yearbook of Agriculture* reported that approximately 35 million acres of formally cultivated land had been rendered unfit for crop production, 100 million acres of land had lost all or most of its top soil and an additional 125 million acres continuing under cultivation were also losing topsoil. On Sunday, April 24, 1935, the worst of the black blizzards, *"Black Sunday,"* occurred. By December of 1935 it was estimated that 850 *million tons* of topsoil had been lost from the southern plains in that year alone. As the drought continued, the area affected increased from 4.35 million acres to 5.35 million acres (Dust Bowl 2001). Areas of southwestern Kansas accustomed to receiving 18 inches of rain per year were reduced to below ten inches during the 1934-37 period. Yields were down 46 percent during this period (Riney-Kehrberg 1989). To mitigate the situation, many governmental programs and services were initiated, among which was the Soil Conservation Service. Extensive effort was expended in *"re-plowing the land into furrows, planting trees in shelterbelts, and other conservation methods."* By 1938 these measures had resulted in a 65 percent reduction in the amount of blowing soil. Finally, in 1939 the drought was broken (Dust Bowl 2001). As the country pulled further out of the depression and with the commencement of World War II, the Dust Bowl devastation diminished, and the land was restored to productivity. But the damage done the region was extensive and lasting. The average loss of farm population in southwestern Kansas was 30.5 percent with lows of 18 percent (by county) ranging to a high of 53 percent. Most of the people leaving the area were young. A *"fault line"* appeared at age 40 to 50. All cohorts above this line gained in percent of total



(Dust Bowl 2001
Figure 15 Dust Bowl area, 1931-1939.

population. These displaced *"Okies"*, (some of them were from Kansas and Texas) so poignantly described in John Steinbeck's immortal novel *The Grapes of Wrath* (1939) tended to migrate west. At one time their numbers became so great that in February 1936 the Los Angles Police Chief dispatched 125 policemen to the Arizona and Oregon borders to patrol with the purpose of preventing *"undesirables"* from entering California (Dust Bowl 2001). It is impossible to prove a negative regarding the number of tractors not sold as a result of the Dust Bowl, but it is safe to say that this natural disaster coupled with the Great Depression contributed significantly to tractor production declines during the 1931 to 1939 period (Clarke 1991).

EXAMINING SOME DIFFUSION PHENOMENA

Use of the normal distribution curve of adoption rate and the S-curve of cumulative adoption are examined here. Five categories of adopters and the five attributes of a technology experiencing diffusion are also examined. Rogers (1995) uses these two categories of attributes of the diffusion phenomena to explain many of the facets of diffusion as described on a generic basis.

Categories of Adopters

Rogers (1995) frames his discussion of categories of adopters by stipulating that any such set of categories must satisfy three criteria. They must be exhaustive so as to include all potential members of the adoption population. They must be mutually exclusive so that each adopter may unambiguously be assigned to a single category. Finally, they must be derived from a single classificatory principle. In his categorization, he identifies five such categories: innovators, early adopters, early majority, late majority, and laggards. In the past, however, other categories were proposed and used. Rogers (1958, 345-6) noted that titles of *"innovators, community adoption leaders, local adoption leaders, and later adopters"* were used as well as *"early adopters, informal leaders, non-adopters, progressives, conservatives, traditionalists, and diehards."* Rogers then describes each of his five categories in idealized terms, ascribing generic characteristics to each. It is also important to consider that, while the adopter categories address personality traits, that membership in a given category relative to a specific innovation does not imply a similar categorization with regard to another innovation. Hence, an early adopter of technology might well become a late majority or laggard relative to a new fashion fad based on his or her specific personal interests, familial situation or economic condition at the time.

The five categories are summarized below with an emphasis on adoption of a technological innovation, but not the tractor specifically.

Innovators

These people are considered to be venturesome almost to the point of obsession. Frequently such people form a clique of like-minded friends to the relative exclusion of others in their community where *"community"* may extend beyond geographical constraints. A networked group of like-minded geographers might thus be considered a community. Geographical distance between such individuals may be great, but the bonds of this personality overcome the distance. The innovator of a technological innovation must be capable of understanding technical concepts in an abstract fashion. In addition to such abstraction, he or she must further demonstrate an ability to cope with uncertainty, thus forcing decisions without the knowledge of the innovation's characteristics available to later adopters. Depending on the innovation, the innovator may need considerable financial resources, not only to absorb the cost of being early, but also to cover the possibility of the failure of a given innovation to meet its promise. While the innovator may be considered somewhat outside the mainstream of his or her community, he or she serves as a gatekeeper in introducing new ideas and technology into the social system.

Early Adopters

Rogers (1995) characterizes early adopters as local in orientation and respected within the society. He defines the early adopter as a strong opinion leader, and hence the type of individual most sought out by change agents. The degree of local respect accorded the early adopter allows him or her to influence the remaining groups (particularly those nearest to them in the social structure) within a society simply by their own personal adoption and the perceived objective evaluation of the consequences of the adoption. It is as a result of the early adopter's positive decision that the critical mass required for take off of adoption is initiated.

Early Majority

It is with the early majority that the full critical mass of adoption is achieved. This group, deliberate in its judgements and actions, bridges the gap between early adopters and the mean of the adoption process. Individuals within this group would rarely be considered to be opinion leaders within their society. With reference to this group, Rogers (1995, 252) quotes Alexander Pope: *"Be not the first by which the new is tried, nor the last to lay the old aside."* The early majority, in keeping with their deliberate personality, has a relatively longer time of deliberation before making the adoption decision (Rogers 1995).

Late Majority

As with the early majority, the late majority makes up about one third (34 percent by Rogers' definition) of a society. Coming as they do immediately after the mean point of adoption has been reached, they differ little from the early majority except in degree. They act more deliberately and with more skepticism in their adoption decision process. The late majority will be influenced by their peer group's earlier adoption. The late majority will not generally be considered an opinion leader within his or her community, but rather an opinion follower. The uncertainty factor must be removed before a late adopter considers it safe to adopt. Obviously, the critical mass of adoption will have been achieved before the late adopter takes the plunge (Rogers 1995).

Laggards

Laggards, by definition, lag behind the rest of a society in opting to adopt an innovation. Rogers (1995) characterizes this group as being the most localized in their outlook. Another word might be provincial. Provincial also connotes one with a traditional (at least within his or her own society) outlook, looking to the past for guidance. Laggards tend to have an extended innovation-decision process and associate most frequently with like-minded individuals – thus retarding the adoption process further. Laggards frequently are at the lower end of the economic ladder, having fewer resources available with which to affect a break with past custom.

However, laggards may simply be slow to adopt or fail to adopt because of personal consideration. A 94 year-old individual may choose to retain a dial-type telephone as opposed to a touch-tone, cordless simply because he or she has had such a telephone since his or her family first got a phone in the 1920s or 30s and sees no particular advantage to a touch tone unit personally. For perhaps 50 years men continued to shave with a straight razor after the advent of the safety razor simply because that was the way they started shaving when a teenager. Hence, *"laggard"* may carry a pejorative connotation, or may imply simply the relative time of adoption supported by the best of personal reasons or preferences.

Characteristics of Innovations

Individual innovations are considered to exhibit a set of characteristics or attributes which influence the who, when, where, and how of the diffusion process of that innovation. The *"rate of adoption"* is Rogers' term (1995, 206) for these four facets of the adoption process. He characterizes rate of adoption as:

> *. . .the relative speed with which an innovation is adopted by members of a social system. It is generally measured as the number of individuals who adopt a new idea in a specific period ... So the rate of adoption is a numerical indicator of the steepness of the adoption curve of innovation.*

Rogers (1995) identifies five factors affecting the rate of adoption: the perceived attributes of an innovation, the type of innovation decision (optional, collective, or authority), the communication channels available, the nature of the social system, and the extent of promotional efforts by change agents. Of most interest at this point in this discussion of diffusion are the five perceived attributes of an innovation to be considered by each of the five categories of adopters. The five attributes include: relative advantage, compatibility, complexity, trialibility, and observability.

Relative Advantage

This attribute is very much a perception of the individual adopter and the nature of the innovation. Rogers (1995) makes the point that relative advantage may be of a personal, social, and/or economic nature. Relative advantage for current fashion may simply involve being the first in your community to adopt the latest fashion proclamation, and the attendant envy of one's peers.

Rogers (1995, 213) specifically addresses relative advantage in an agricultural situation wherein he quotes Griliches on the adoption of hybrid corn in 1957 on the basis of the innovation's potential for profitability as:

> *It is my belief that in the long run, and cross-sectionally, (sociological) variables tend to cancel themselves out, leaving the economic variables as the major determinates of the pattern of technological change.*

Thus, in the case of a technological innovation, it appears that Rogers supports the thesis that economics plays a dominant role in the perception of relative advantage.

Rogers also raises the issue of potential "*over adoption,*" whereby an individual makes a decision in favor of adoption when, in fact, this is not the wisest and most rational choice. When, therefore, economics are acknowledged to be the dominant factor in technological innovation, one can only assume that a perceived rational decision was made on the basis of an incorrect perception of the economics and that over adoption resulted. Over adoption may well lead to what Rogers (1995, 182) refers to as *"discontinuance."* Quoting, he says: *"Discontinuance is a decision to reject an innovation after having previously adopted it."* In the case of a major technological innovation such as the agricultural tractor, the option of discontinuance may not be viable.

Compatibility

This attribute may well have its roots in the subconscious. Rogers (1995) discusses at length the issue of compatibility of an innovation vis-à-vis existing values, past experience, and the individual need of the potential adopter within a society. The more closed the society, the more dominant will be existing values. Amish societies in the United States are famous for adhering to a lifestyle at odds with contemporary America based on custom and belief. Similarly, past experience will dominate the current decision process when societal members have been little exposed to outside influences and ideas. The individual needs of the adopter will vary, but on a very conscious level, on the individual potential adopter. Hence, as long as perceived relative advantage is positive, an adopter will be receptive to an innovation when his or her basic belief system is not compromised.

Rogers (1995) also notes that compatibility must consider previously introduced ideas. Once having made the decision to adopt an innovation, a potential adopter will be slow to reverse direction in favor of a potentially more advantageous innovation that forces the individual to dramatically change his or her posture regarding a previous decision. The adage in business that one should never chase sunk costs requires an adopter to not only leave expected return on investments unrealized, but also to reject a previously perceived rational decision.

Complexity

The complexity of an innovation is very much in the eyes of the individual adopter. Rogers (1995) expresses this as the individual adopter's mental positioning of an innovation on a simplicity-complexity continuum. He then proposes a generalization to the effect that the complexity of an innovation is inversely related to the rate of adoption within a social system. What must be stressed, however, is that complexity in this context relates only to the perception of complexity by the adopter. Highly complex technological innovations may appear simple to the adopter if its *use* is viewed as simple. Cell phones and GPS units come readily to mind. Unfortunately, in the case of new technology, early models of an innovation must frequently be refined to reduce the apparent complexity as viewed by the would-be adopter. This, in turn, will skew the normal distribution curve negatively, with a resulting decline in the slope of the S-curve and an extension of the time required to achieve a critical mass for take-off.

Trialibility

Trialibility, as the name implies, is the extent to which an innovation may be experienced first-hand before an adoption decision is made. Rogers (1995) notes that the ability to try an innovation under one's own conditions and under one's own hand gives added meaning to an innovation and tends to dispel uncertainty. He suggests that the trialibility of an innovation is positively related to the rate of adoption of an innovation within a social system. In most instances, the trialibility of an innovation increases over time, so that the late majority and laggards have more opportunity to try an innovation (either personally or vicariously) than do the innovators, early adopters, and early majority. Rogers then conjectures that this allows the laggards to progress more rapidly from trial to adoption than earlier adopters.

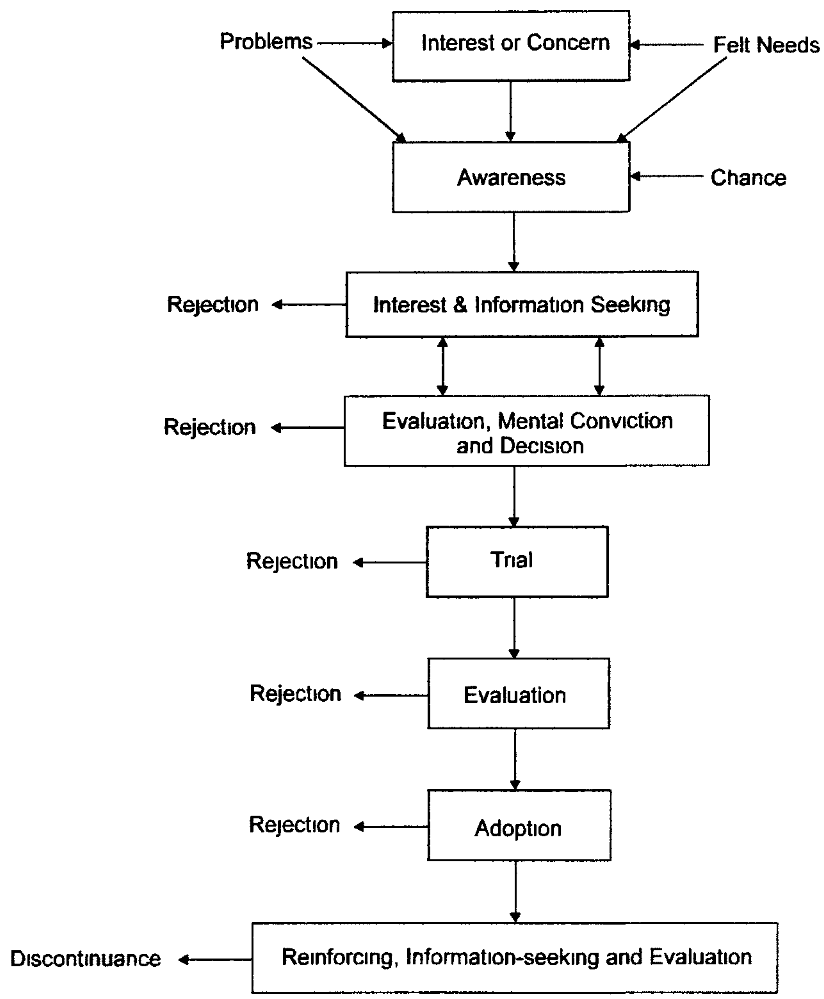
Observability

The observability of an innovation is the degree to which the results of adoption can be observed. Results may be instantaneous or delayed. Also, results may be simply quantified and easily communicated to others, or results may be complex and difficult to convey. To emphasize this point, Rogers (1995) asserts, particularly for a technological innovation, that there is a hardware component and a software component. He defines the hardware component as that part of the innovation having a physical or material existence. He defines the software component as the information base regarding an innovation. A problem of semantics here is that the term "*software*" carries a somewhat different connotation within the computer community from which it emerged in the 1960s. To avoid this difficulty in semantics, the two components of a technological innovation will be referred to in this thesis as the physical and the intellectual aspects.

It is to the *intellectual* observability that Rogers (1995, 244) postulates that: *"The observability of an innovation, as perceived by members of a social system, is positively related to its rate of adoption."*

THE INDIVIDUAL DECISION PROCESS

In addition to the characteristics and propensities of the individual adopters and the attributes of the innovation under consideration, a number of authors (Beal et al 1957; Hassinger 1959; Jones 1967) have examined the process followed, to some degree or another, by the individual adopter in arriving at an adoption/rejection/discontinuance decision. Figure 16 shows a variation on Jones' decision process schema. As indicated in the figure, the process normally starts with the recognition that a *problem exists* or that a *need is felt*. While, perhaps, initiating below the level of consciousness, this problem or need may lead to an *interest or concern*. The problem, need or interest then may lead to an *awareness* of a condition amenable to a solution. *Interest and information seeking* follows after the potential adopter becomes aware of an innovation which may address his or her problem or need. At this stage the available information may cause *rejection* of the innovation based on a rational evaluation of the individual's needs and personal conditions. However, with information at hand, an evaluation and decision can be made to either reject or continue to a *trial* period. The trial period may be personal or vicarious, but acts in the mind of the potential adopter as a test of the applicability of the innovation under consideration. If the innovation passes the trial phase, an *evaluation* is



(Jones 1967, 9)

Figure 16. The individual adopter's decision process.

then a rational next step. The potential innovator must reconcile his or her economic and personal situation with the potential implied by the trial period. Both acceptance and progress to the *adoption* phase and rejection of the innovation are options. If all evaluation continues to exhibit a positive vs. a negative balance then adoption becomes the rational decision. However, rejection continues to be an option. Finally, experience will either produce a positive *reinforcement, information-seeking, evaluation* reaction –

implying a continued use of the adopted innovation, or a rejection of the innovation – now in the form of discontinuance (Rogers 1995). Obviously, the process with the individual adopter may progress monotonically from one of the indicated phases to the next, or one or more phases may be skipped. Similarly (though not shown in Figure 16), re-entry into the decision process may be made by a potential adopter who, for rational reasons, may have exited the process at a previous time through rejection.

Thus it may be seen that each individual in any of the five adopter categories must pass through some version of the decision process in route to making his or her adoption decision. The path and timing of the decision are influenced by the five characteristics of the individual innovation and the aforementioned considerations of exogenous forces (familial, societal, economic, and political/governmental) impinging on the individual's unique progress through the decision process. This will occur regardless of the time in the overall adoption process that the individual enters the decision process. An individual may be inclined by personality and intellect to be, say, an early adopter. Personal or economic considerations may force this individual out of the adoption process (through rejection). A later re-entry and ultimate adoption may place the individual into an early or late majority adopter category without altering the overall progression through the decision process.

THE S-CURVES OF POTENTIAL ADOPTERS, POTENTIAL FOR EXCESS PROFITS, AND THEORETICAL AND ACTUAL RISK

Arnold (1998) points out that an Iowa farmer finds himself or herself in a much different market than does the tractor division of Ford Motor Company. Whereas Ford operates in an oligopoly:

> *. . . a theory of market structure based on three assumptions: few sellers and many buyers, firms producing either homogeneous or differentiated products, and significant barriers to entry.*
> (Arnold 1998, 528)

the Iowa farmer must survive in a perfect competition market. This market definition is predicated on four assumptions (Arnold 1998):

There are many buyers and sellers (firms or individuals) in the market; none of whose activities are large in relation to total purchasing or selling.

Each individual (or firm) produces a homogeneous product. A farmer may produce more than one crop but *within its individual market,* wheat or corn from one farm is not differentiated from the wheat or corn from the adjacent farm once its in the silo.

Buyers and sellers alike have at their disposal all of the relevant information regarding the condition of the market – pricing, product quality and quantity, sources of supply, time of availability, etc.

There are no barriers to entry or exit. While there may have been a significant original investment in the real estate (and farm real estate is generally considered a good investment), an individual farmer is free to shift from one cash crop to another from year to year without incurring any significant amount of out-of-pocket expense.

Returning to Figures 4 and 5, it is informative to superimpose the normal distribution and the S-curve (logistic) of cumulative adoption. In this presentation (Figure 6), one notes that the point of maximum slope of the S-curve is reached at the vertical line intersecting the normal distribution curve at its peak. This would be so regardless of any positive or negative skew.

Operating as he or she does in a perfect competition market, there are still some avenues available to the farmer for increasing net income – all of which carry some element of risk. Increasing acreage of one crop under cultivation (at the expense of another crop) may increase net returns, but only if the cost of producing the selected crop is more than offset by additional income. Under the perfect competition model the farmer is free to do this without fear of compromising the market price, since his or her output is not great relative to the total market. This type of substitution also presupposes that the farmer is not shifting the crop paradigm away from the Von Thunen core/periphery model by substituting, say, strawberries for wheat (Jordan-Bychkov 1999). Two risks must be confronted in this situation. For various climatic and/or entomological reasons the newly favored crop may become a poor producer that year and the farmer would have been better off focusing on another crop; or the harvest is bountiful, but other farmers have also harvested bumper crops and the market is glutted.

A second potential for increasing net returns is through the adoption of innovation. If successful, this option will provide the farmer with greater net returns (through greater gross income or reduced costs, or both) for some period of time until the adoption process is complete and the market price is driven to its equalization price by the nature of the perfect competition model. This option also carries risk. The innovation may not work as anticipated. Initial capital investment in the innovation, out-of-pocket expenses, labor hours of time, and lost cash crop revenue are all potential risks. Hence, there is a factor of risk corresponding to the potential for excess profits working from the point of adoption by the individual until the completion of the adoption process.

Figure 17 replicates Figure 6 with two additional curves. A second S-curve is shown having multiple functionality. This curve is an inverse (mirror image) of the cumulative adoption curve. First, the curve represents the pool of potential adopters. Obviously, at the start of any diffusion process there is a pool of potential adopters as perceived by interested parties, as change-agents. As adopters opt for the new innovation, the pool of potential adopters decreases. Hence, the sum of the potential adopters and the sum of cumulative adopters at any point along the time axis must equal a normalized value of 1.00 (100 %).

This second S-curve also represents the theoretical risk associated with adoption and the potential for excess profits. The theoretical risk and potential for excess profits may also be considered as inversely proportional to the state of adoption. In the case of risk, this assumes that the risk associated with adoption decreases with each adoption,

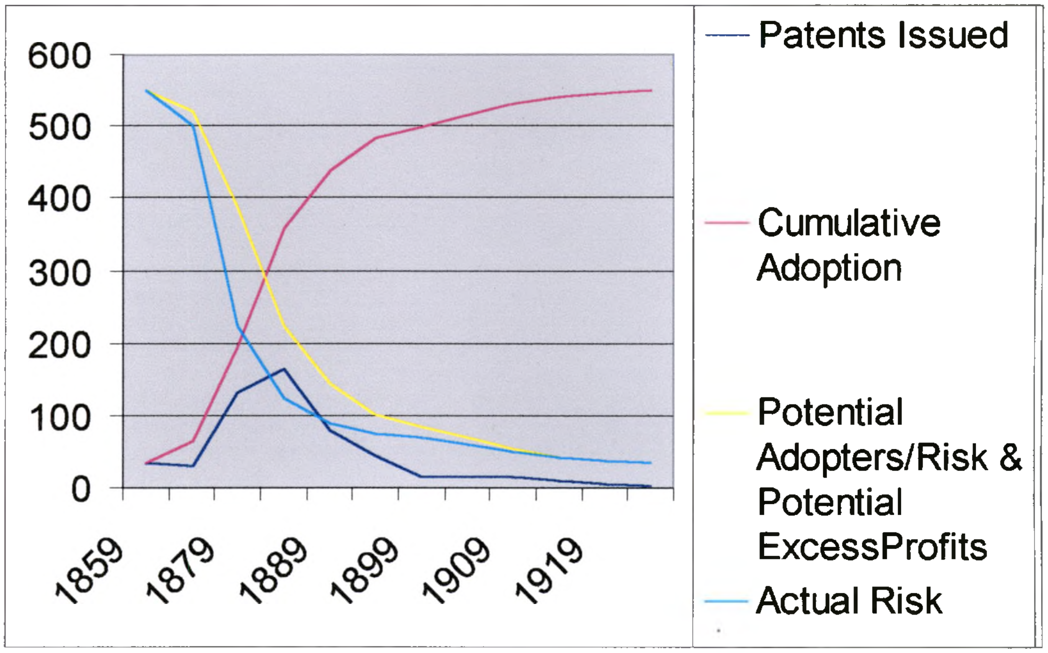


Figure 17. Actual and theoretical curves relating to the adoption process for the sulky plow, 1855-1923.

thus the next adopter faces less risk than those who have gone before. It also means that the potential for excess profits also decreases as price adjustments occur under the perfect competition model. Additionally, the point of intersection of the two S-curves also occurs at the point where these two curves intersect the vertical line through the peak of the normal distribution curve. As observed in Figure 6, this point occurs after the point of take-off (also referenced as the point of critical mass) in the adoption process. At this point adoption is proceeding at a sufficient rate and magnitude such that it is not likely to stop. Hence, as the process of adoption proceeds, the risk and potential for excess profits associated with adoption are reduced proportionately to the cumulative adoption.

Finally, an additional line is presented (yet another S-curve) in Figure 17 representing the actual risk an adopter was assuming at the time of his or her adoption decision. At the time of adoption, the farmer cannot know the actual risk being assumed.

In the case of highly successful technological innovations, as hybrid corn in the period 1930 to 1942 (Ryan 1948), or the agricultural tractor from 1907 to 1954, the actual risk may well have been substantially less than the potential risk. Hence, the line for actual risk in Figure 17 is drawn such that actual risk is below theoretical risk (of course, the reverse could be true – actual risk could be greater than theoretical risk). Events (Clarke 1991) do, in fact, show that farmers were hesitant to adopt even in the face of apparent relative advantage favoring the tractor. Lew (2000) accounts for this delay in his diffusion model for the tractor by the inclusion of a *"delay factor"* attributed to market uncertainty during the critical 1920s and 1930s. In a much broader context, Oster (1999, 25) simply comments that: *"On average, people are risk averse."* Such an aversion translates into hesitancy in assuming the risk associated with adoption of a technological innovation regardless of the associated potential for excess profits. In Figure 17 this phenomena may be observed by selecting a year (say 1889) and observing the vertical distance between the actual risk and the theoretical risk curves. The length of the line presents a graphical representation of the magnitude of risk aversion in influencing the time of adoption. Similarly, a horizontal line drawn between the actual risk and theoretical risk curves indicates the time delay in which actual risk would have been encountered rather than the theoretical time at which the farmer actually adopted. The area under the potential excess profits curve delineated by this horizontal line thus represents the potential excess profits forfeited by the farmer based on the time of adoption vs. the time adoption could have taken place at the same true level of risk.

EXAMINING THE DIFFUSION OF THE AGRICULTURAL TRACTOR

This examination of the diffusion of the agricultural tractor focuses first on the determination of the years during which the various adopter categories were actually making their adoption decisions. This is accomplished by using the yearly tractor production to determine the cumulative production on a yearly basis. For purposes of this thesis, cumulative tractor production is used as a surrogate for market penetration through to the mid-fifties. Using Rogers' (1995) percentages for defining adopter categories, the years in which the first three categories were making their decision to adopt are identified. Superimposing the events of the day onto the years of adoption allows examination of the decision process by each of the adopter categories. The presumption here is that the individual adopters based their decisions on the characteristics of the innovation and the then-current real world conditions confronting them.

Secondly, based on the results of this examination, an association index has been assigned for each combination of adopter category and characteristic of the innovation. This information is presented in matrix form and conclusions drawn from the character of the matrix thus constructed.

Tractor Production from 1907-1950 and the Normal Distribution and S-Curves of Diffusion

For purposes of this diffusion study the period from 1880 to 1907 is considered to be the era of the steam traction engine. This period is not considered as part of this discussion (steam traction engine manufacture actually continued until 1924 when J. I. Case ceased production (Letourneau 1997; Erb and Brumbaugh 1993)). The steam traction engine did play an important role as a catalyst in creating demand for more energy in the field, but this era of the tractor is considered outside the scope of this discussion of diffusion. By 1907 there were internal combustion powered tractors in the field, but their number in relation to the number of farms would have been trivial. Table 26 shows a compendium of information regarding tractor production in the United States from 1907 to 1950. This table presents yearly and cumulative production for the years of the table. These numbers are then equated to total market penetration by the agricultural tractor. During the early years this would account for most tractors sold since the number of these tractors vs. the number of farmers already owning a tractor was miniscule. Whatever second hand market had sprung up during the period is assumed to translate into a farmer having purchased a used tractor as his or her first tractor rather than purchasing a new one. This would also account for farmers who traded in a tractor for a later model and their trade-in then contributed to supplying the used market. The number of tractors junked by a farmer who then purchased a new one tends to overstate the total market penetration as does tractors manufactured for export. However, these considerations are deemed consistent in projecting actual market penetration during this period. Cavert (1956) uses USDA, Agricultural Research Service data indicating significantly fewer actual tractors on farms than simple cumulative production would

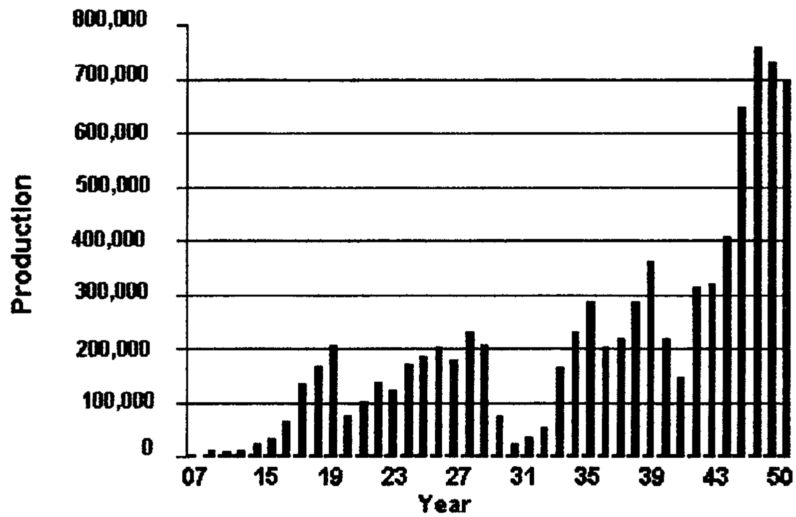
TABLE 26
UNITED STATES TRACTOR PRODUCTION, 1907-1950

Year	Production	Cumulative Production	Adopter Category	Year	Production	Cumulative Production	Adopter Category
1907	600	600	Innovators	1931	71,704	2,298,775	Early Adopters
1912	11,000	11,600	Innovators	1932	* 20,000	2,318,775	Early Adopters
1913	7,000	18,600	Innovators	1933	* 35,000	2,353,775	Early Adopters
1914	10,000	28,600	Innovators	1934	* 50,000	2,403,775	Early Adopters
1915	21,000	49,600	Innovators	1935	161,131	2,564,906	Early Adopters
1916	29,670	79,270	Innovators	1936	227,185	2,792,091	Early Majority
1917	62,742	142,012	Innovators	1937	283,155	3,075,246	Early Majority
1918	132,697	274,709	Innovators	1938	199,223	3,274,469	Early Majority
1919	164,950	439,659	Innovators	1939	215,462	3,489,931	Early Majority
1920	203,207	642,866	Early Adopters	1940	283,546	3,773,477	Early Majority
1921	73,198	716,064	Early Adopters	1941	358,520	4,131,997	Early Majority
1922	99,692	815,756	Early Adopters	1942	215,074	4,347,071	Early Majority
1923	134,590	950,346	Early Adopters	1943	143,000	4,490,071	Early Majority
1924	119,305	1,069,651	Early Adopters	1944	310,990	4,801,061	Early Majority
1925	167,553	1,237,204	Early Adopters	1945	317,268	5,118,329	Early Majority
1926	181,995	1,419,199	Early Adopters	1946	402,413	5,520,742	Early Majority
1927	200,504	1,619,703	Early Adopters	1947	643,567	6,164,309	Early Majority
1928	175,934	1,795,637	Early Adopters	1948	753,623	6,917,932	Early Majority
1929	228,976	2,024,613	Early Adopters	1949	726,975	7,644,907	Early Majority
1930	202,458	2,227,071	Early Adopters	1950	693,646	8,338,553	Early Majority

* - Estimated
(Letourneau 1993, 18, 27, 86, 120, 143)

indicate. However, the shape of the resulting S-curve is consistent with that implied by Table 26. Also, the relative degree of accuracy for the USDA numbers based on sampling over the years is probably lower than that for production figures compiled from manufacturing company records over the same period. Clarke (1991) uses yet a third set of numbers purported to represent the number of tractors purchased in the U.S. from 1910 through 1939. Again, these numbers are lower than the production figures, but duplicate the trends indicated by Table 26. Erb and Brumbaugh (1993), without quoting a source, specify 1915 production at 30,000 and 1925 production at 200,000. These numbers track closely with Letourneau's numbers. The USDA identifies 1954 as the year when tractors exceeded draft animals on farms in the U.S. (USDA 2001). Here one has to assume a macro view, since the size of the farm and the location would have played a significant role in determining the mix of horses vs. tractors on any one farm. However, the year 1950 would approximate the fifty-percent point of market penetration. The analogy of cumulative production corresponding to market penetration would have started to break down during the 1950s. From this point forward the number of farms with multiple tractors increased; the number of used tractors on the market increased; and the power and versatility of tractors increased relative to the draft animals being replaced. Finally, from the 1960s and 1970s, the number of horses and mules retained for recreational purposes accounted for virtually all such animals remaining on farms and were, therefore, irrelevant to market penetration. Herding of cattle in extremely rough and brushy terrain is one activity still practiced on horseback.

Figure 18 shows the base data from Table 26 in chart form. The bar chart portion of the figure shows the raw production figures year-by-year. The crest of the bars

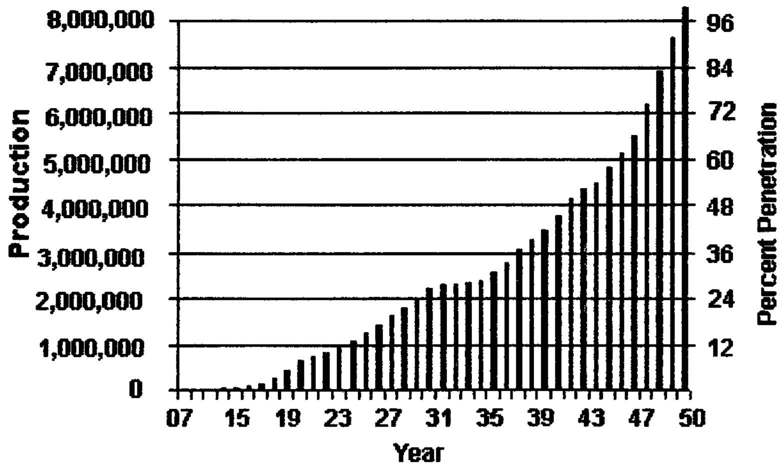


(Letourneau 1993, 18, 27, 86, 120, 143)

Figure 18. Tractor production base data, 1907-1950.

indicates the first half of a normal distribution curve – thus lending credibility to the assumptions that tractor production corresponded to market penetration during this time period, and that the termination of the curve in 1950 roughly approximates the mean point of the normal distribution curve - fifty-percent market penetration.

Figure 19 shows the cumulative production contained in Table 26. Based on the fact that the production figures of Table 26 indicated the first half of a normal distribution curve, the cumulative production figures must indicate the first half of an S-curve (logistic) as indeed they do. The scale on the left indicates actual production. The scale on the right indicates percent of total production. Rogers' definition of innovators as 2.5

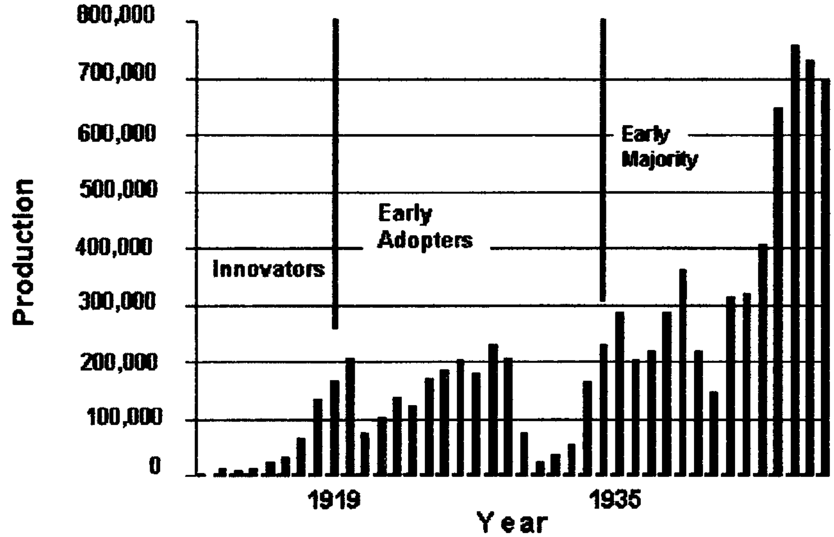


(Letourneau 1993, 18, 27, 86, 120, 143)

Figure 19. S-curve of cumulative tractor production, 1907-1950.

percent of all adopters was then used to define the years in which innovators were making their decision. Since only fifty-percent of the total normal distribution curve is being utilized, the percentage is normalized to 100 percent by doubling 2.5 to 5.0 percent. Five percent of total production (0.05 x 8,338,553) is 416,928. This level of market penetration was reached in the 1919-1920 period. Thus in Table 26, the period 1907-1919 is indicated as innovator years. Similarly, Rogers defines early adopters as 13.5 percent of the normal distribution curve. Normalizing 13.5 percent yields 27 percent. Adding the previous market penetration of 5 percent indicates that the break-over point between early adopters and early majority would be 32 percent of cumulative production (0.32 x 8,338,553) or 2,668,337. This cumulative production was reached in the 1935-1936 time period. The remaining 68 percent of cumulative production is relegated to early majority (8,338,553 – 2,668,337 = 5,670,216). Table 26 reflects this determination.

Figure 20 shows the normal distribution of production with the innovator, early adopter, and early majority categories indicated.



(Letourneau 1993, 18, 27, 86, 120, 143)

Figure 20. Normal distribution curve with adopter categories indicated.

Figure 21 then shows the first half of the normal distribution curve with the most significant world conditions of the period indicated. These would be the real world conditions confronting each of the adopter category individuals at the time they were actually making their decision. These conditions included early experimentation and early market penetration by tractors, the World War I years and commensurate boom, the post World War I agricultural depression overlaid by the 1920s economic boom (the roaring 20s). This, in turn, was followed by the Great Depression with the Dust Bowl exacerbating the situation for a significant portion of the Rural Heartland and beyond. World War II interrupted

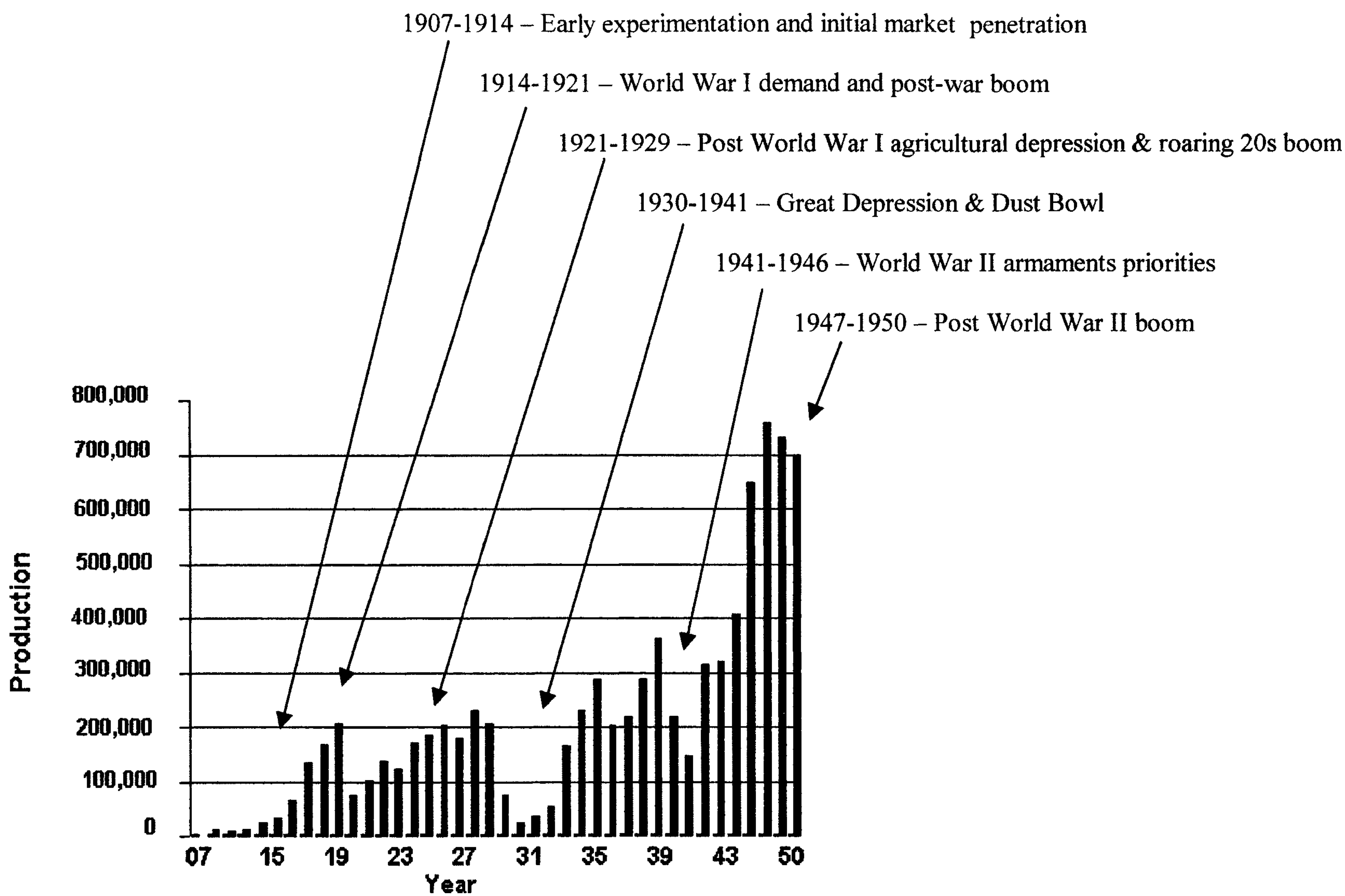


Figure 21. Tractor production with exogenous forces as incentives and barriers to production, 1907-1950.

manufacturing as war priorities were imposed on industry. Then following World War II, an economic boom period benefited both the economy as a whole and the agricultural economy in particular.

Superposition of current events onto the normal distribution curve (and hence its ogive) to explain the irregularities experienced in real-world diffusion situations is strongly supported by Pemberton (1937, 55). He states:

> *. . . cultural changes take place in response to definite patterns of cause and are characterized by typical regularities. A further knowledge of the nature of these typical orders in culture change will lead eventually to an ability to predict the rates and limits of specific changes.*

He demonstrates this hypothesis through examination of four cases of disparate types of diffusion – including that of the ratio of passenger car registrations to total population in the U.S. from 1908 through 1934. In his example he plots actual registration ratios versus a pure logistic curve for the period. Extremely close agreement is achieved from 1908 until 1928 whereupon a slackening of the slope is noted. From 1930 until 1932 the slope becomes negative. From 1932 until 1934 the slope again turns positive, but at a low value not experienced since the 1910 timeframe during the initial tail of the logistic curve. His conclusion is that the Great Depression caused the deviation and that this impact is measurable through the deviation from the logistic curve. However, in his other examples (two of which include a deviation resulting from World War I) he notes a return to the close correlation with the logistic curve within a few years. From this he concludes:

> *The general conclusion, from the few cases available for the study, is that the pattern of causes determining the adoption of a culture trait are so persistent that, in case of the curve of diffusion is distributed by a social crises, the passing of the*

> *crisis will find diffusion accelerating or retarding in rate, so that the curve will resume the expected course within a short period of time.*
> (Pemberton 1937, 56)

The flattening of the curve shown in Figure 19 during the depression years matches this conclusion for the case of the agricultural tractor. Thus Pemberton concludes that economic depression and war may cause a short-term deviation from the expected pattern of diffusion. In this thesis we add drought and economic boom to his list of causative events as noted in Figure 21.

AN ASSOCIATION MATRIX OF CHARACTERISTICS OF AN INNOVATION VIS-À-VIS ADOPTER CATEGORIES

The following discussion presents a subjective evaluation of the importance of each of Rogers' characteristics of an innovation in the decision process of each of the five adopter categories. The results of the evaluation are presented in matrix form at the end of the chapter after a discussion of the individual index entries used to populate the matrix. The last two categories defined by Rogers are the late adopters and laggards. Their adoptive decisions are extrapolated to have occurred during the 1950s – 1960s time period – a time of general prosperity as regards farming operations generally (the 1950s drought not withstanding). As part of this discussion, a numerical value is assigned each of the 25 adopter category/innovation characteristic combination. The numerical, or association index, is scored from 1 to 4 as follows:

1 Little or no consideration of this characteristic in the decision process
2 A consideration, but likely to be overshadowed by other characteristics during the course of the decision process
3 A significant consideration in the decision process
4 A very important consideration in the decision process

An assumption in all the following analysis is that the decision-maker considering adoption of an agricultural tractor was basing his or her decision on a rational analysis. The implication of a rational decision varies depending on the characteristic under consideration regarding purchase a tractor.

Characteristics of the Innovation Process as Experienced by the Individual Farmer

Relative Advantage

As discussed earlier, rationality here implies a decision made on an economic basis, and to a lesser extent on quality of life considerations for the farmer. The economics are simple: increase net returns either through increasing gross returns, decreasing costs, or both. Being the first in a social system simply has no place in assessing the relative advantage of a technological innovation. Complicating this, the innovator has no precedence upon which to judge the veracity of future actions.

Compatibility

Adoption of a farmer's first tractor would have been at odds with all previous familial, social and life experiences. Motive power in the field had been provided by draft animals for thousands of years. The farmer of the 1907-1950 era was, with few exceptions, the son or daughter of generations of farmers. Family and societal custom, tradition, and practice revolved around the selection, care, feeding, and use of draft animals. During the earlier part of the diffusion process, a break with this extensive past would have been major, condemned by traditionalists, and open to second-guessing by the less forward thinking. In order to address the issue of compatibility, analysis vs. dogma is assumed here on the part of the farmer.

Complexity

This characteristic, as discussed earlier, must be viewed as the complexity of use as viewed by the adopting farmer. The two features of tractor utilization of interest would be daily operation of a tractor vs. a team of draft animals, and the routine maintenance of a tractor vs. the care, feeding and grooming of a stable of draft animals and associated tack. In the following analysis, note that the perceived complexity of equipment involving an internal combustion engine would have decreased significantly over time as millions of cars and trucks were themselves diffused throughout the nation during the latter four decades of the examination period.

Trialibility

In examining the diffusion of the agricultural tractor it must be remembered that the rational farmer desperately wanted to adopt any innovation which would reduce the drudgery of farming. Two such aspects were spring plowing and harvest. In the case of the tractor, the trialibility was inversely proportional to the passage of time (refer to the theoretical risk line discussed relative to Figure 17). For each year that passed, the farmer who had not yet made the adoption decision had that much more vicarious experience in the time saving and labor saving aspects of tractor utilization. Particularly in the case of harvest, labor saving is desirable. However, the ability to get the harvest in, regardless of effort expended, in the minimum period of time when the weather and the maturity of the crop are at their maximum state of desirability would have been a compelling vicarious experience for the farmer.

Observability

Finally, the rational farmer had much to gain from observation of the successes and failures of neighbors who had previously made the adoption decision. For the farmer, observability had two components. He or she was at once able to observe the time and labor savings achieved by previous adopters. The monetary advantages of tractor operation and maintenance vs. the care, handling and feeding of draft animals would have required, perhaps, multiple years to be conclusive. Negative experience of the non-adopter would also have played an important role. The farmer who was unable to get a crop in before fall rains while adoptive neighbors reaped the rewards of optimum harvest completion would have experienced observability at its most painful and expensive reality.

Association of Characteristics of Adoption and Adopter Categories

The following discussion presents a subjective determination of and association index for the intersection of adopter categories with each of the characteristics of the adoption process as experienced by the individual farmer at the time of his or her adoption decision.

Innovators

The agricultural tractor innovator would have made an adoption decision during the period 1907 to 1919 (Table 26, and Figure 20). The exogenous forces of this period included early experimentation and initial market penetration followed by the agricultural demands of World War I with its attendant pressure to increase agricultural production (Figure 21). The innovative farmer would have been a leader in the community. Such leadership may not have been social, but would have, by necessity, been financial for at least two reasons. First, the innovator had to have the financial resources to purchase a tractor without the support of potential lenders (bankers in particular and lenders in general were, and are, fiscally conservative and are not themselves natural innovators). If the banker of the time was willing to loan the money required for purchase of a tractor, then the adopter probably did not *require* such support in the first place. Second, he or she would have had an economic need great enough to justify the significant outlay for the purchase of a tractor, hence, he or she would typically have had significant landholdings. Intellectually the farmer would have been among the elite of the community - requiring the ability of abstract projection of technological innovation to commit significant monies to purchase. Perhaps the most significant attribute of the innovator in the adoption process of the agricultural tractor was an ability (or nature) to go beyond popular wisdom of the time – seeking new solutions to the energy problems created by the technological advances of the 19th century.

Innovators/Relative Advantage

This characteristic would have been a dominant consideration in the decision process of the would-be innovator. By being first, perhaps of anyone the adopter knew or had met, he or she would be forced into the personal conviction that the relative advantage *to him or her* was so great as to overwhelm the importance of the other four characteristics. In making his or her decision to purchase an agricultural tractor, the would-be adopter may have seen a steam traction but not a gasoline traction engine or at least very few. With whatever experience he or she did have available, the farmer would have had to extrapolate perceived benefits to his or her own operation. At this point in the first two decades of the twentieth century, the perceived benefits would have included faster (or more extensive) plowing, and faster harvesting. Since this would have been in the form of an experiment, the farmer would have had to maintain all or most of the farm's draft animals. First, the original agricultural tractors were not envisioned as a total replacement for draft animals (most farmers of the period would have still utilized a wagon for hauling and a buggy for personal transportation). Secondly, a number of agricultural chores were not originally performed with a tractor (plowing being the most obvious). Finally, draft animals were needed as a fallback, and feed crop acres were required for their maintenance. Thus, to take this bold step, the innovator would have had the financial means for purchase, plus the farm operations to realize the potential benefits coupled with the ability to maintain draft animals in reserve.

Association index value: 4.

Innovators/Compatibility

With draft animals having provided the motive power throughout agricultural history, it is difficult to assert that any significant amount of compatibility existed relative to existing values, part experiences, and individual needs for the innovator (Rogers 1995). A tractor would have been at odds with the familial and societal mores of the period where a farmer's judgement at selecting and an ability to handle draft animals were significant criteria in judging acumen and manhood. Rogers (1995) also notes that compatibility involves consideration of previously introduced ideas. With few previous ideas (other than the steam traction engine) compatibility would not have been of significance to the innovator.

Association index value: 1.

Innovators/Complexity

After generations of growing from boyhood to adulthood learning to manage teams of draft animals and the associated tack, the care and maintenance of an internal combustion engine powered tractor would have been a wrenching break with the past. The innovator may, however, have viewed this as a challenge rather than a deterrent. In Dinsmore's (1922) diagrams of the hitching of eight horses in tandem, twelve horses in tandem, and seven horses abreast, however, the innovative farmer may have perceived that large teams of horses had reached their practical limit due to complexity and time-consuming maintenance of tack and the draft animals themselves. All-in-all, the innovator would likely have significantly discounted complexity in the decision process.

Association index value: 2.

Innovators/Trialibility

The innovator would have had little or no ability to experience first-hand the utilization of a tractor until after the adoption decision was made. Further, with little contemporaneous experience with operation and maintenance of internal combustion powered vehicles (as automobiles or trucks); the success of a tractor on essentially duplicate farms adjacent to one another would depend on the eye of the beholder. In order to make a decision in favor of a tractor, the innovator would have had to discount trialibility to insignificance – he or she was going to provide the trialibility for those that followed.

Association index value: 1.

Innovators/Observability

The agricultural tractor innovator would have been forced to develop the intellectual aspect of the innovation on his or her own. Observability would come only with the successful/unsuccessful use of the equipment. Results would not be delayed. Time/manpower saved in plowing would be instantaneously observable. The ability of the tractor to complete a plowing or harvesting without catastrophic maintenance problems would be delayed only the days or weeks until the task was complete. Later adopters would have the benefit of this experience, but the innovator would be forced to evaluate observability on the fly, but by then the adoption decision had been made and the tractor was in the field.

Association index value: 1.

Early Adopters

The early adopter of the agricultural tractor would likely have had the same needs, desires, and resources of the innovator, but would simply have been slightly more deliberate in the decision process. This could stem from personal orientation, family situation, current economics or a combination of all. The adoption period for the early adopter would have been from roughly 1920 until 1935. By the latter part of this period the early adopter would have had some personal experience with cars and trucks. This period was dominated by dramatic economic swings. First came the agricultural depression following World War I, coupled with the general economic boom of the roaring 1920s. To a large extent, the agricultural sector failed to benefit from the 1920s boom as most of the decade was spent recovering from the post World War I depression. The Great Depression caused a precipitous drop in tractor production and sales. Superimposed on the Great Depression was the Dust Bowl (1931-1939). But tractors *were* being sold during this period (refer to the tractor wars of 1921-23 (Williams 1992b)) and it would have been the early adopter making the adoption decision in spite of the economy.

Early Adopters/Relative Advantage

Relative advantage would have been as important to the early adopter as to the innovator. The early adopter might or might not have access to a previous adoption decision by an innovator. As a somewhat more conservative individual than an innovator, the early adopter likely would, in fact, need an even greater perception of relative advantage than the innovator because there would be less inclination to try something simply because it was new. This individual would require a strong perception that the tractor would significantly enhance farm productivity and/or enhance quality of life. Likely he or she would have had conversations with other potential early adopters and peer group early majority. The early adopter would move with more consideration and less whim than the innovator. That said, the Great Depression governmental programs (Clarke 1991) coupled with the wild economic swings (technological advancement of the tractor relative to a draft team, decline in the cost of farm labor and feed, plummeting crop prices, and Dust Bowl loss of productivity) presented the early adopter with a complex relative advantage consideration.

Association index value: 4.

Early Adopters/Compatibility

As with the innovator, the early adopter farmer would have disregarded or rejected issues of compatibility in the context of existing values, past experience, and individual need. Since the early adopter would have been working from few previously introduced (new) ideas, he or she would have been willing to go against societal perceptions that *"this is the way it has always been done."* A major difference between the innovator and early adopter, however, was the presence of automobiles and trucks on the farms, roads and streets of America. By 1920 even a farmer from the nation's most remote locales would have experienced in some fashion cars or trucks (and probably tractors). Veterans of World War I would have had first-hand experience in using and maintaining vehicles with internal combustion engines. By the end of 1920 Henry Ford alone had manufactured 4.7 million Model Ts and reached a maximum production of 2 million units per year in 1923. By the end of production in 1927, 15 million Model Ts had been placed on the roads and farms of the U.S. (Model T 2001). The presence of these and other vehicles would have removed much of the mystery and reluctance of the farmer to adopt the tractor in lieu of draft animals in just the same fashion as automobiles were replacing horses and buggies.

Association index value: 2.

Early Adopters/Complexity

Whereas the innovator may have viewed the complexity of the tractor as a challenge, the early adopter would have been more restrained in his or her analysis. The sheer magnitude of the adoption decision would have given the early adopter some pause. The early adopter would have considered the logistics of support, including fuel, lubricants, spare parts, and consultation on repairs. While perhaps having supreme confidence in an ability to operate the new machinery, consideration would have been given to the fact that he or she personally would not always be either operating the equipment or supervising its operation. Overall, complexity and its concomitant ramifications would have been more of an issue than for the innovator. During the 1920-1935 time frame, however, the distribution systems for tractors, parts, fuels and lubricants would have paralleled that the automobile (albeit on a smaller scale). There would have been less concern on the part of the early adopter regarding an adequate support network than that experienced by the innovator.

Association index value: 3.

Early Adopters/Trialibility

While having more of an opportunity for trial than an innovator, the early adopter would still be depending on intuition to a large degree. Until the advent of the smaller tractor, spearheaded by the Fordson F in 1918, gasoline traction engines were viewed primarily as being in competition with the steam traction engine and its market. With the introduction of the Fordson F, and followed shortly by International Harvester's Farmall (Williams 1992a), the tractor came to be viewed as a competitor with the horse. This opened up the market for change agents and allowed manufacturers to go more into the field where the farmer was most comfortable. Contests began to be held in which competing equipment could be observed in the field under identical conditions (Pripps and Morland 1994). Also, the Nebraska Testing Laboratory began operations in 1920 and by 1935 had tested 248 different tractor models (Wendel 1993). Whereas trialibility was not an option for the innovator, there was some opportunity for consideration by the early adopter.

Association index value: 2.

Early Adopters/Observability

The characteristic of observability would have had a similar impact on the early adopter as for the innovator. The primary difference would have been that the early adopter would have had more opportunity to see a tractor demonstration, a contest, or a field trial (such as at local and state fairs). Lack of opportunity could have restrained the early adopter in his or her ability to observe a tractor in operation and judge its performance vis-à-vis his or her own operations.

Association index value: 2.

Early Majority

The early majority was making its adoption decision in the years from roughly 1937 to 1950. As noted in Figure 21, conditions and thus actions and decisions were influenced by the latter years of the Great Depression, the end of the Dust Bowl, World War II production constraints, followed by the post World War II boom. These were years of tremendous change in the world and in the agricultural picture in the United States. During these years the U.S. became a nation operating on the energy of the internal combustion engine. Automobiles and trucks had displaced buggies and wagons. Airplanes had begun displacing trains. Trains themselves were segueing from steam locomotives to diesel electric.

Outside the Rural Heartland, the Plantation South was undergoing a major transmogrification. Prunty (1955) defines this area as extending along the coastal plane and alluvial valleys between Richmond, VA and the lower valley of the James River to the lower Brazos River of Texas – ultimately encompassing 350,000 square miles of the South. In the ante-bellum period, this was the area of slave labor supported large landholding. In the post-bellum years these landholdings fragmented into two subtypes (the share-cropper and tenant-renter farmer types). Following World War II there was a major migration of farm laborers out of this area. Prunty (1955, 483) explains this as a: *"response to the attractive urban-industrial wages in both northern and southern cities."*

This change in the labor availability ushered in the *"neoplantation"* where, without the share-croppers and tenant farmers, the plantation was once again de-fragmented. The landholder was, for the first time, attracted to the tractor as opposed to the mule.

Garrett (1990) discusses the propensity of the southern landholder to select the mule over the horse – despite the mule's higher purchase price. The contracts (generally verbally) between landholder provided for the landholder supplying draft animals to share-croppers, and by extension the tenant farmers tended toward mules. The mule was acknowledged to be capable of sustaining greater abuse than the horse. Garrett references one authority (1990, 926) as saying:

> *Although there are no data on the relative incidence of disease between horses and mules in southern agriculture, during World War I the ratio of illness in horses to mules was six to one.*

Additionally, while a horse will eat and drink until it is sick if provided with enough oats and water, the mule will eat only what is necessary. Thus, the landholder was heavily influenced to supply mules to sharecroppers who were more likely to abuse the animals than the landholder. This same inclination would have continued whereby the landholder provided mules rather than tractors, based on the belief that mules would hold up under abuse better than a tractor.

The availability of the row-crop, moderately priced, mass-produced tractor placed these landholders squarely in the early majority adopter category, but for very different reasons than other parts of the country.

The early majority would have had the opportunity to be influenced by community opinion leaders and/or change agents whom the farmer trusted and respected.

Hence, his decision process would have involved a broader set of options than those available to the innovator or early adopter.

Early Majority/Relative Advantage

Relative advantage remained a strong factor in the adoption decision of the early majority. However, this group had, in most cases, innovators and/or early adopters to observe. The relative advantage of these groups could be analyzed in a vicarious fashion. Relative advantage remained a dominant factor, but the would-be early majority had more basis for analysis and hence the overall decision process rested more on perceived relative advantage than for earlier adopters.

Association index value: 3.

Early Majority/Compatibility

Compatibility would have remained a factor in the decision process of the early majority. However, with examples set by earlier adopters, the *"this is how it has always been done"* syndrome would have been significantly diminished. The early majority would have had the example and endorsement of the earlier adopters, particularly the opinion leaders amongst this group. The effect of this previous experience and the vicarious experience of tractor ownership would have been to allow the compatibility issue to be more a part of the decision process, since the early majority now had a baseline against which his or her personal experiences could be judged.

Association index value: 2.

Early Majority/Complexity

Whereas the earlier adopters would have disregarded complexity (or even considered it as a positive challenge), the early majority would be more concerned about an ability to master the new technology. If this were not so, he or she might well have been an early adopter. At the same time, the early majority decision maker would have had more experience available from peers and the community opinion leaders in determining both how to overcome the complexities of tractor operation and maintenance. Additionally, he or she would have had an enhanced ability to judge personal capability in conquering these complexities.

Association index value: 3.

Early Majority/Trialibility

Here the early majority decision maker would have had considerably more opportunity to observe and experience first hand (through either assisting neighbors or receiving their assistance) the trialibility of the tractor under circumstances similar to his or her own. Thus, trialibility would have been an enhanced option for evaluation and the rational farmer would have taken significant advantage of this availability.

Association index value: 3.

Early Majority/Observability

Having waited some number of seasons to enter the decision process (or having reached a negative decision previously) the early majority farmer would have had considerable ability to see and evaluate daily tractor performance in the field, and the delayed benefits of completing a plowing or harvest. Required maintenance, both routine preventive as well as seasonal and major work-over, would also have been observed by the early majority.

Association index value: 3.

Late Majority

By the time the late majority farmer entered the decision process sometime later than 1950 at least 50 percent and perhaps as many as 83 percent of the farming community would have decided on the switch to an agricultural tractor. Its pros and cons in every facet of operation and benefits would have been experienced not only by the community's opinion leaders (the innovators and early adopters), but near-peers amongst the early majority. The late majority member had much more experience and information available for consideration than did the first 50 percent of the social system. Gunlogson (1957, 162) indicates (Table 27) the dispersion of tractors amongst three groups of farmers in 1955.

TABLE 27
FARM INCOME AND TRACTOR DISPERSION IN THE U.S., 1955

Farm Categories	Annual Farm Income 1957 Dollars	*Annual Farm Income 2001 Dollars	Number of Farms	Number of Tractors	Percent Farms w/Tractors in Category
Group A	>= $2,500	>= $15,813	2,101,000	3,348,164	** 100
Group B	1,200 – 2,499	7,590 – 15,806	763,000	627,781	82.3
Group C	< 1,200	<7,590	1,919,000	209,260	10 9
			4,783,000		
				4,185,205	

* (Economic History 2001)

** Virtually all farms in Group A would have had at least one tractor. Many farms would have had 2 or more tractors.

Gunlogson notes that the census reported that only 2,525,206 farms reported having a tractor, so since the total number of tractors reported was 4,185,206, this means that many farms had more than one tractor. It was estimated that the farms in Group A had 80 percent of all the tractors, Group B had perhaps 15%, while Group C had less than 5% of the tractors reported. In terms of 2001 dollars, farms in Groups B and C would have been populated by part time farmers, or farmers who at least augmented their income off the farm.

Finally, as noted earlier, Cavert (1956, 19) comments that:

> *In contrast with the situation in 1910, or even in 1930, by 1955 mechanization has progressed to the point that a farm relying on horses is a fit theme for the Sunday supplement.*

Thus, by the 1950s, the diffusion pattern was becoming increasingly difficult to ascertain and characterize due to the multiple tractor ownership/part time farmer phenomena. However, based on the exogenous forces of the 1950s and 1960s, the following characterization of the late majority adopter are presented.

Late Majority/Relative Advantage

Relative advantage would have continued to be important, but would be losing its importance in the face of experience by earlier adopters. With more than half of a farmer's neighbors having opted in favor of the tractor, only very personal situations relating to family or economics would be applicable in the relative advantage decision process.

Association index value: 2.

Late Majority/Compatibility

With a critical mass having long since been achieved, and take-off underway, compatibility may well have reversed its role in the decision process. Instead of the later adopter being concerned with breaking with the past, existing values, past experience (albeit recent experience), and individual needs would be *favoring* adoption. In other words, the late majority might well have felt community pressure in favor of adoption in order to remain part of the main stream in the social system. Hence, compatibility would have remained a significant factor, but for opposite reasons from the earlier adopters.

Association index value: 3.

Late Majority/Complexity

The late majority would now be familiar with the complexities of tractor operation and maintenance. Again, personal concerns by the individual farmer would be dominant. Social pressure would now be pushing in favor of the farmer proving an ability to master the tractor, whereas earlier adopters would have had to view complexity as a challenge, or evaluate complexity in light of their own propensity.

Association index value: 3.

Late Majority/Trialibility

Trialibility would have maintained its importance as the late adopter was able to observe the total process of tractor adoption, not only in tractor operation and maintenance, but in the conversion of feed acres into money crop acres as the tractor truly became a competitor with the horse. The simple availability of information would have encouraged the rational evaluation of the tractor's trialibility.

Association index value: 3.

Late Majority/Observability

Observability is, perhaps, the most enhanced of the characteristics available to the late majority not previously available to the earlier adopters. Both instantaneous and delayed results were available from opinion leaders, peers, and printed matter such as the farm gazettes. The late adopter had the luxury of other's previous experiences in their decision process. He or she would likely have carefully considered the observable benefits during the decision process.

Association index value: 3.

Laggards

The laggards would, in general, either have been extremely cautious, or more likely, have had familial, or economic considerations which had previously held him or her back from either the initial decision process, or had made a previous negative decision. One example of such an individual would be an older farmer, working a few acres for personal use, who was simply happy to finish out his or her days behind a beloved horse or mule.

Many would have been from areas of the country where the adoption process came late. The Plantation South fits this scenario. While this area has been considered as part of the entire country for purposes of diffusion in this thesis, specific economic conditions relating to sharecroppers and tenant farmers, made this area something of a separate entity. Subsequent analysis might well focus on this area to determine if a discernable normal distribution curve and S-curve on adoption could be developed for this particular geographic area.

Laggards/Relative Advantage

Based on the fact that laggards are frequently on the lower rungs of the economic ladder, relative advantage is harder to achieve, but not a major cause for concern in the decision process. At this point, with at least 84 percent of the population of the community having purchased a tractor, relative advantage would have been determined – even for the small landholder with limited economic means.

Association index value: 1.

Laggards/Compatibility

With most of the community having gone before, societal norms would now be greatly in favor of a positive decision as a vehicle for conformity. Also, for the laggard personality, he or she could use compatibility as an excuse for a positive decision.

Association index value: 4.

Laggards/Complexity

Whatever mysteries of the new technology, they would have been greatly relieved by the time of the laggard. Perceived community esteem might also have played a part. Also, by this time, the laggard would almost certainly have owned an automobile and would have had plenty of opportunity to operate and perhaps maintain the new equipment.

Association index value: 3.

Laggards/Trialibility

As with complexity, the laggard likely would have had hands-on experience with operation and maintenance. The experience level would have been high and significant consideration would have been given to trialibility

Association index value: 4.

Laggards/Observability

Observability would, perhaps, have been the most decisive characteristic of the decision process. The laggard had years of vicarious experience in observing both immediate and delayed results of tractor utilization. With, perhaps, the least amount of imagination of all the adopter categories, the laggard would have depended on the experience of others in encouraging a position decision process.

Association index value: 4.

THE ASSOCIATION MATRIX

The results of the association index assignments are shown in Table 28. While admittedly subjective, the association index summations seem to support what intuition might have indicated.

TABLE 28
ASSOCIATION MATRIX FOR THE DIFFUSION OF THE AGRICULTURAL TRACTOR

	Relative Advantage	Compatibility	Complexity	Trainability	Observability	Totals
Innovators	4	1	2	1	1	9
Early Adopters	4	2	3	2	2	13
Early Majority	3	2	3	3	3	14
Late Majority	2	3	3	3	3	14
Laggards	1	4	3	4	4	16
Totals	14	12	14	13	13	

The totals column shows a monotonically increasing association index sum for the five adopter categories. This would be consistent with the farmers of the time making rational decisions based on the information available at the time they were in the decision process.

The innovator had little experience available, and so made a decision on the basis of personal inclination coupled with a subjective evaluation of relative advantage. By the time the laggards were in the decision process a significant amount of information and community experience was available. Thus more of the characteristics could be utilized in the decision process.

The totals row shows consistency in the value achieved for each characteristic with values ranging from 12 to 14. This implies that under this evaluation that each characteristic cumulatively received equal consideration in the decision process, with no characteristic dominating.

Both these conclusion would appear to support a decision process based on realistic adopter categories and significant innovation characteristics with farmers acting in a rational fashion.

From a geographical view, we know that the process of diffusion has a major areal component. In the determination of the association indices this component was examined as a part of individual index assignment along with the other factors as economy, society, geopolitics, and climatic conditions. In examining the resulting association matrix, while each of these components was considered, none skewed the overall balance of the matrix. Through the structured approach we were also able to incorporate more than one of these components when they worked in concert. For instance, the individual decision process was different for the large landholder in the Rural Heartland from that of his or her counterpart in the Plantation South. Geography separated them, but the components in their individual decision process were the same, thus verifying the value and validity of the association matrix.

CHAPTER 6

CONCLUSIONS

INTRODUCTION

This thesis was conceived as a study of the diffusion of a 20^{th} century technological innovation. Early on, it became apparent that a precursor to the diffusion study was that of how the tractor came to be available for diffusion at the particular point of time in which it occurred. This lead to the analysis of prerequisites required for critical mass to initiate development. As with all technological innovations, the start of development (and hence diffusion) was not a sharply denoted date in history. This thesis has chosen to initiate analysis at the point of chassis mounted steam engines providing the motive power to place the unit in the field in position to perform useful work. The steam traction engine acted as a catalyst in promoting the gasoline traction engine development when the internal combustion engine became a viable alternative to the steam engine. The diffusion study, therefore, was initiated in 1907 when there was a production of some 600 internal combustion engine powered units. Diffusion was examined in the context of the categories of individual adopters, the characteristics of the innovation, and the exogenous forces at work during the period of diffusion. The vehicle for this examination was the creation of an association matrix allowing a structured and simultaneous study of all three aspects of the adoption process.

PREREQUISITES AND DEVELOPMENT OF THE TRACTOR INDUSTRY

A concept fundamental to the development study was that a series of the prerequisites required must be in place before market demand and or innovator initiative can initiate development. This concept is relevant in addressing the question: *"Why did development of a particular innovation start when it did?"* Development itself has been framed in the context of examining the pioneers, pioneering companies and the overall maturation of the manufacturing community. This analysis provided the first block illustrated in the development/diffusion/consequences continuum shown in Figure 7. Its overall importance in indicated by the feedback loops shown in the figure linking both diffusion and consequences back to an on-going development process in a closed loop.

DIFFUSION OF THE AGRICULTURAL TRACTOR

Rogers' (1995) four elements in the diffusion phenomena have been addressed. First, the innovation itself is that of the agricultural tractor, picked as an example of a 20th century technological innovation. Second, communication channels were addressed as vehicles for dissemination of information to each of the innovator categories at the time of their adoption decision. Third, the temporal element for diffusion was confined, for purposes of this study, to the start of diffusion of the gasoline traction engine and terminated at the time tractors exceeded draft animals on the farms of America. Finally, the social system was addressed in the context of development and presentation of an association matrix. Added, however, to Rogers' four components of diffusion is that of an areal component. The association matrix, is a construct in which rows consist of the categories of adopters (innovators, early adopters, early majority, late majority, and laggards), and columns consist of the five characteristics of the innovation (relative advantage, compatibility, complexity, trialibility, and observability). The matrix was populated with an association index for each of the 25 combinations of adopter category and innovation characteristic. The association index represents a subjective determination of the importance of each of the innovation characteristics on each of the adopter categories at the time at which the adoption decision was being made. The social and temporal aspects of the time play a role in each of the index determinations, as did the exogenous forces (economic boom, war, drought, depression) at work at that time. Examining the resulting association matrix and the totals row and column supports the hypothesis that diffusion of innovation analysis is amenable to this approach to a structured analytical examination.

OPPORTUNITIES FOR FURTHER RESEARCH

Two options present themselves for further research. First, rather than examining the U.S. market as a whole, studies could be developed focusing on regional patterns within the U.S. and perhaps internationally. Second, the concept of the association matrix could be applied to other categories of diffusion.

During the course of the thesis, the Plantation South has been singled out as an area exhibiting different characteristics and circumstances from the nation as a whole and the Rural Heartland in particular. Diffusion came later in this region than the rest of the nation. Good reasons for this trend have been postulated, however, no in-depth analysis has been done to verify these thoughts. Other areas of the nation could also be examined, such as California. Here diffusion would have been delayed until the widespread availability of the row crop tractor for use in the Central Valley and other truck gardening areas of the state. Specialized models of the row crop known as orchard tractors were also popular as they became available. New England, with its smaller acreage landholdings, but perhaps earlier exposure to automobiles and trucks on the part of the farmer, might prove to be an area of interest. International markets might also prove of interest. Russia, Western Europe, and India might prove interesting foci for study.

This study has been focused entirely on the agricultural tractor as an example of a technological innovation. More contemporary studies might prove of interest, particularly where market penetration is not yet deemed to have reached saturation. In this case, if total market penetration is less than 100 percent, completion of an association matrix might be used to highlight characteristics of the innovation which should be emphasized by interested parties and change agents to minimize the time required for further diffusion. If, for instance, the study indicates that market penetration has reached the level of early majority, the association matrix might point to specific characteristics of the innovation (relative advantage, complexity, or others) likely to be important to the remaining late majority and laggards. Use of the available communications channels could thus be maximized to bring down the perceived risk, and speed completion of the diffusion process.

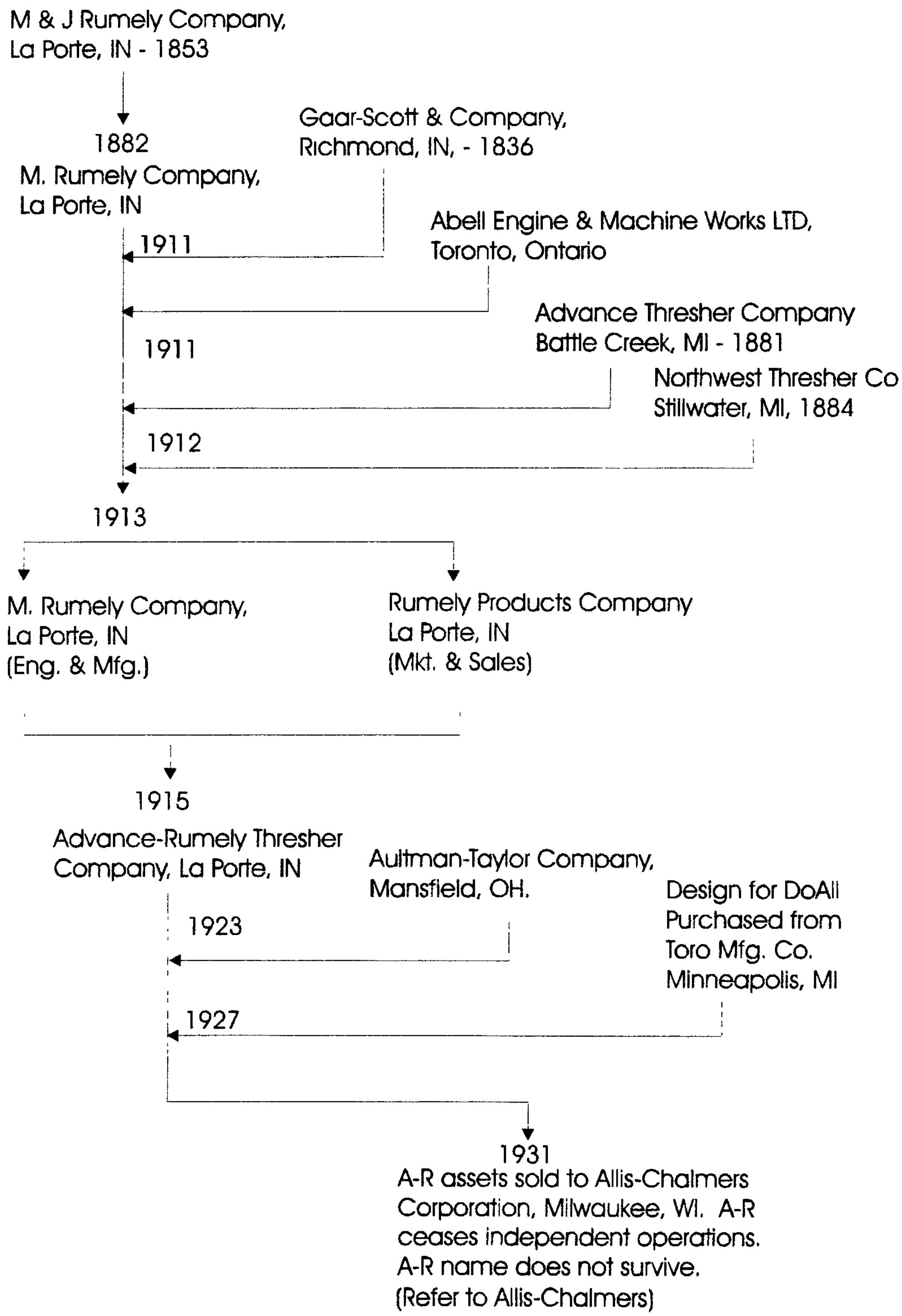
A specific example of technology other than agricultural in nature might be that of the global positioning system, GPS. Depending on the market examined, the diffusion of GPS units is either in its early adopter or at best its early majority phase. A technology-oriented matrix similar to the one developed and presented here, but specifically tailored to GPS, should prove of interest to those seeking its further diffusion (commercial, humanitarian, scientific research, religious). One can envision, for instance, a closed GPS unit allowing the user to know the precise compass setting in order to face Mecca for prayers. Is the relative advantage sufficient to create a market for such a unit? Are there viable uses for a GPS unit equipped with a transmitter, such that the location of the unit (worn or attached) could be determined from receipt of its signal? What would be the relative advantages of such a unit - ability to transmit the location of hikers, offshore boaters, spelunkers, mountain climbers, wild game/endangered/exotic species. What are the complexities of installation? GPS-based location systems for automobiles (for example Cadillac's On-Star system) are in their infancy. If relative advantage is the dominant characteristic of interest to adopters, what are its true advantages, and does the cost justify personal as opposed to commercial use?

Still in the area of technological innovation, but at a much earlier state of diffusion, are hybrid and electric cars (as of this writing fuel cell and other alternative energy sources have essentially zero impact). Here, not only the association matrix, but also the definition of certain characteristics would need reexamination. Relative advantage might not be viewed as economic or enhancing quality of life. Rather, it might be couched in the context of environmental concern/civic duty, and pride. An accurate association matrix could help in determining the characteristics of importance as more of the potential market is penetrated.

Additionally, other types of diffusion, such as religion/ideology, health practices/epidemic, or style/fad, might prove amenable to the association matrix approach. In each of these different types of diffusion, an examination of the definition of characteristics of the innovation would be required. Based on such analysis, a new association matrix could be defined as an initial step in devising a campaign for enhancing the chances of success and reducing the time required for the diffusion process. It is to be hoped that others will examine this structured approach for consideration as an additional arrow in the cultural geographer's quiver in the study of innovation diffusion.

APPENDIX A

TRACTOR FIRM GENEALOGIES



(Epping and Epping 2001; Sanders 1996; King 1989a)

Figure 22. Advance-Rumely Thresher Company genealogy.

1990

Allis-Gleaner (AGCO), Duluth, GA incorporated with purchase of Deutz-Allis Corp, Milwaukee, WI.

↓

1991

Hesston Corporation
Also White-New Idea Tractor Division

1992 → IPO and listing on NASDAQ

↓

1993

Distribution rights for Massey-Ferguson,
also 50% of Agricredit Acceptance Corporation,
also remainder of White-New Idea.

1994 → Massey-Ferguson, also remainder of Agricredit Corporation, also McConnell Tractors. also listing on the NYSE

↓

1995

Distribution rights (North America)
Landini Tractors.

1996 → Lochpe-Maxion, Brazil, also Western Combine Corp. & Portage Mfg., Inc, Canada, also partner with Rabobank Nederland in Agricredit

↓

Continued

Figure 23. AGCO genealogy (Continued).

Continued from previous page

1997

Deutz Argentina, S.A.,
also Fent, Germany

1998

Joint venture with Deutz AG to
produce engines in Argentina,
also SPRA-Coupe, also Willmar

1999 → Estimated sales worldwide $2.9 billion

2000

Hay and Forage Industries (HFI),
Hesston, KS

→ Present

(Pratt 1985; AGCO 2001)

Figure 23. AGCO genealogy.

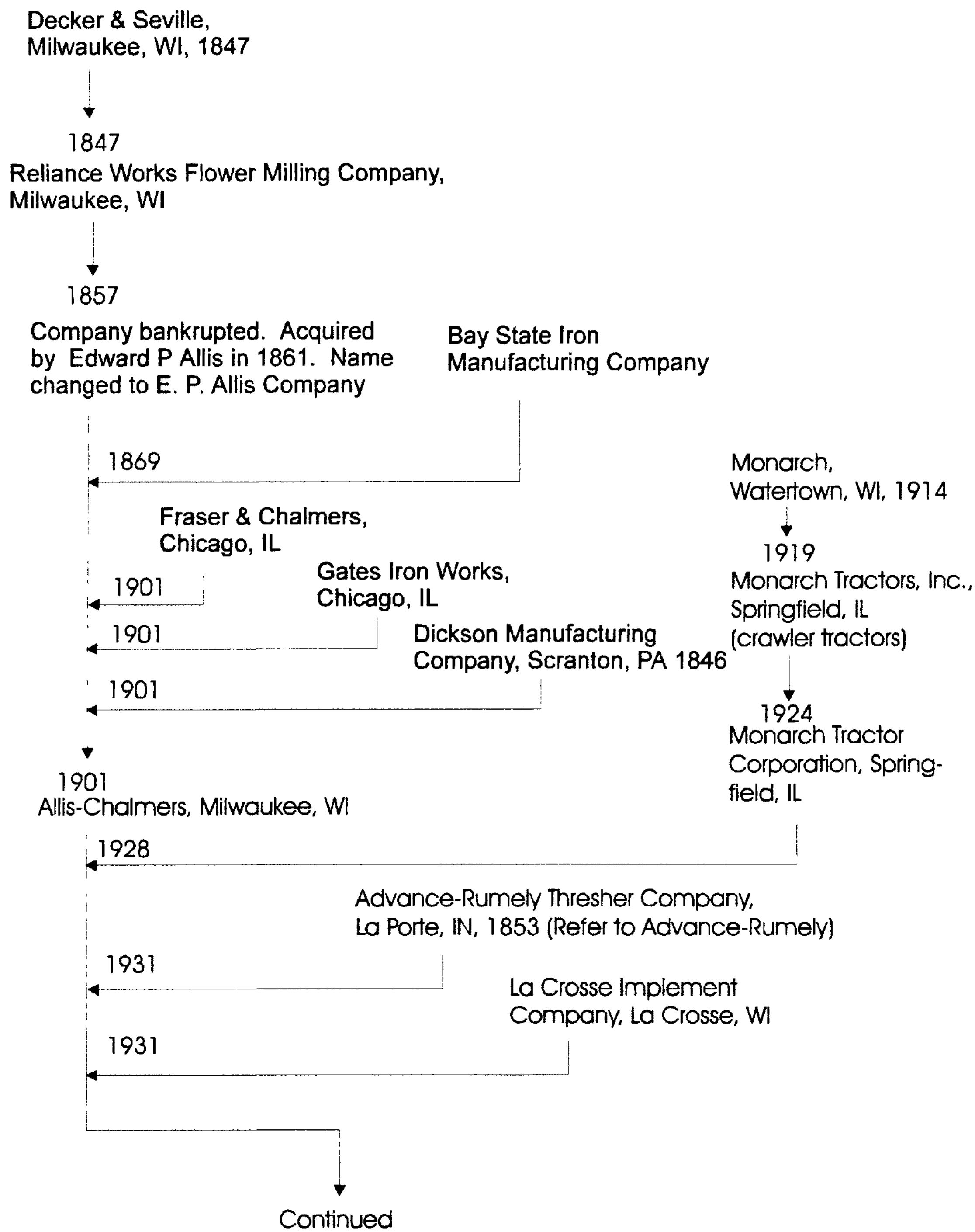


Figure 24. Allis-Chalmers Manufacturing Company genealogy (Continued).

Continued from previous page

1987
Allis-Chalmers announces restructuring plan. Files for bankruptcy protection.

1974
Fiat-Allis Construction Machinery, Inc.

1988
Allis-Chalmers sells most assets: Several businesses to Sweden's Boliden AB, AC Power Generation services to AC Power, Generation Service Acquisition Corp., and Pump business to ITT.

1989
West Allis plant closes.
Allis-Chalmers ceases operations.

1990
Klockner-Humbolt-Deutz (KHD) Cologne, Germany purchases the agricultural equipment division of A-C and forms Deutz-Allis Corp. Milwaukee, WI (Refer to Deutz-AG)

(Sanders 1996; Swinford 1996; King 1989a; Wendel and Morland 1992)

Figure 24. Allis-Chalmers Manufacturing Company.

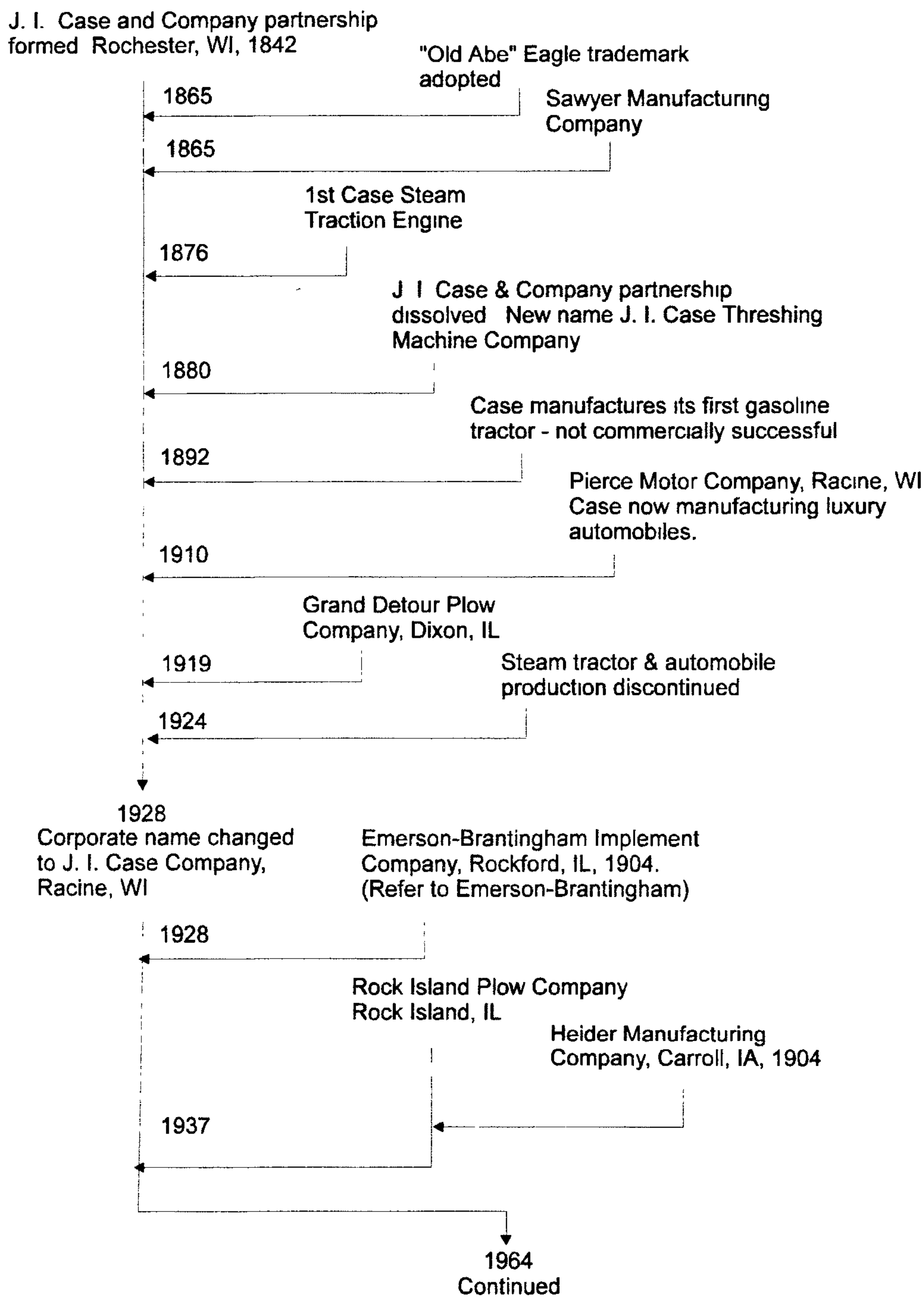


Figure 25. J. I. Case Company genealogy (Continued).

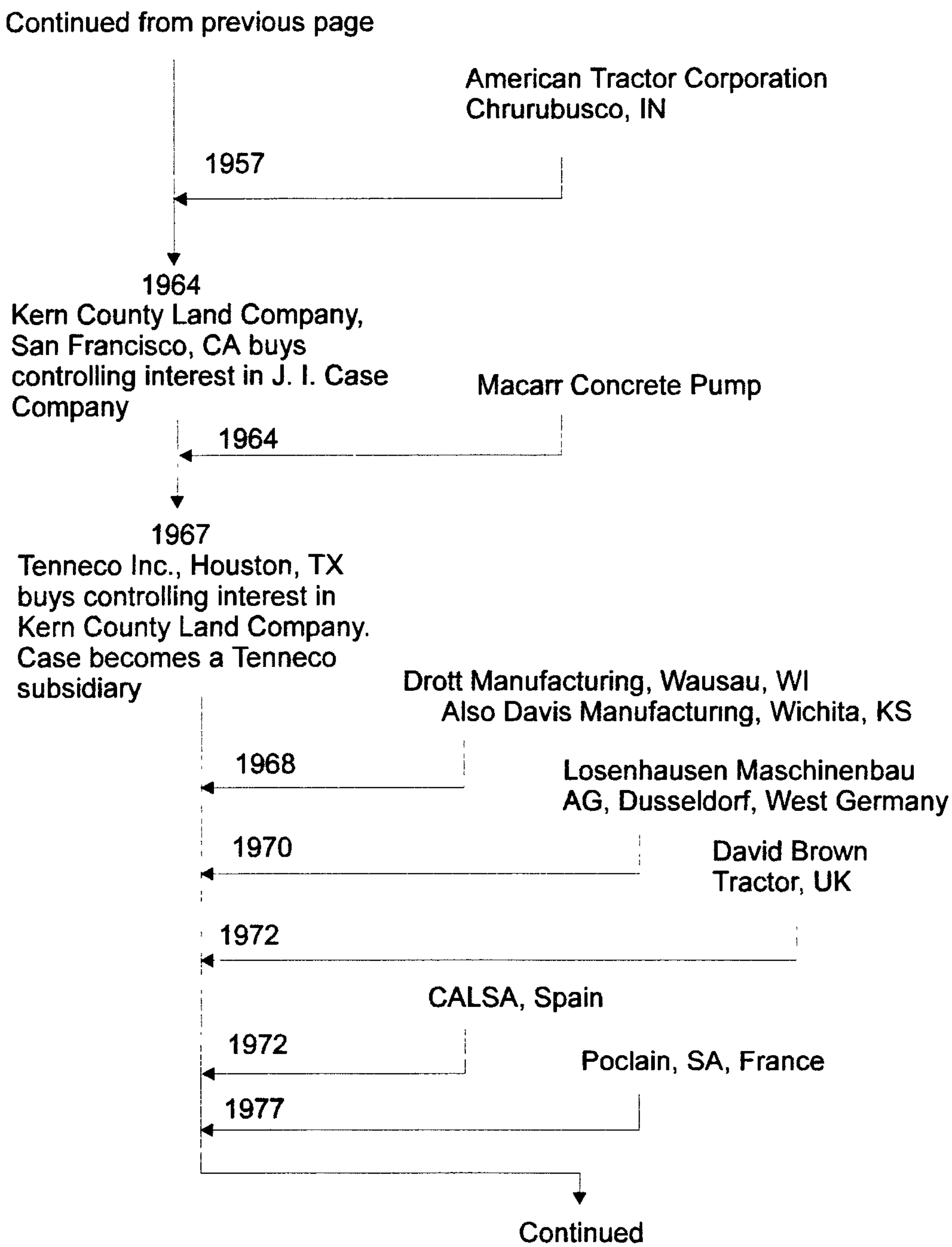
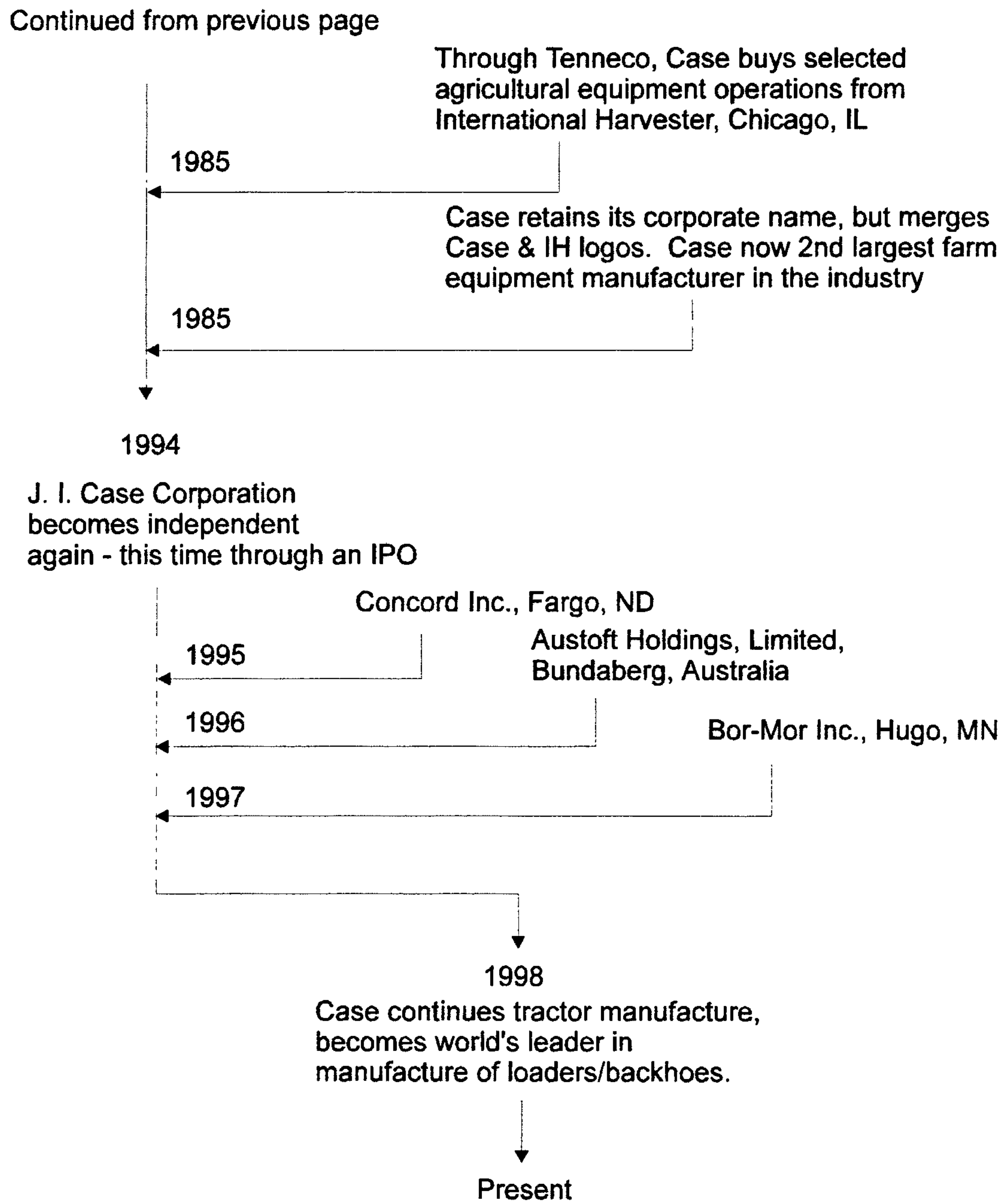
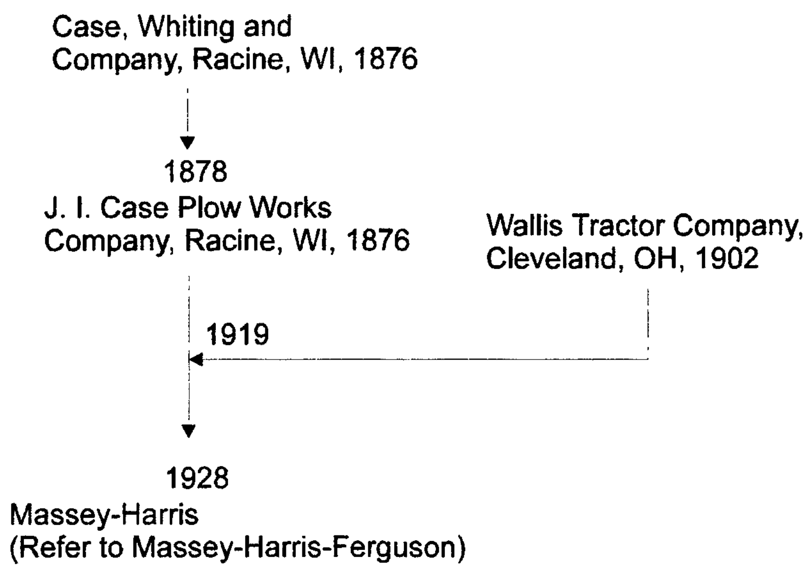


Figure 25. J. I. Case Company genealogy (Continued).



(Sanders 1996; Steam 1999; Case Corporation 2001; Erb and Brumbaugh 1993)

Figure 25. J. I. Case Company genealogy.



(Erb and Brumbaugh 1993; Sanders 1996)

Figure 26. J. I. Case Plow Works genealogy.

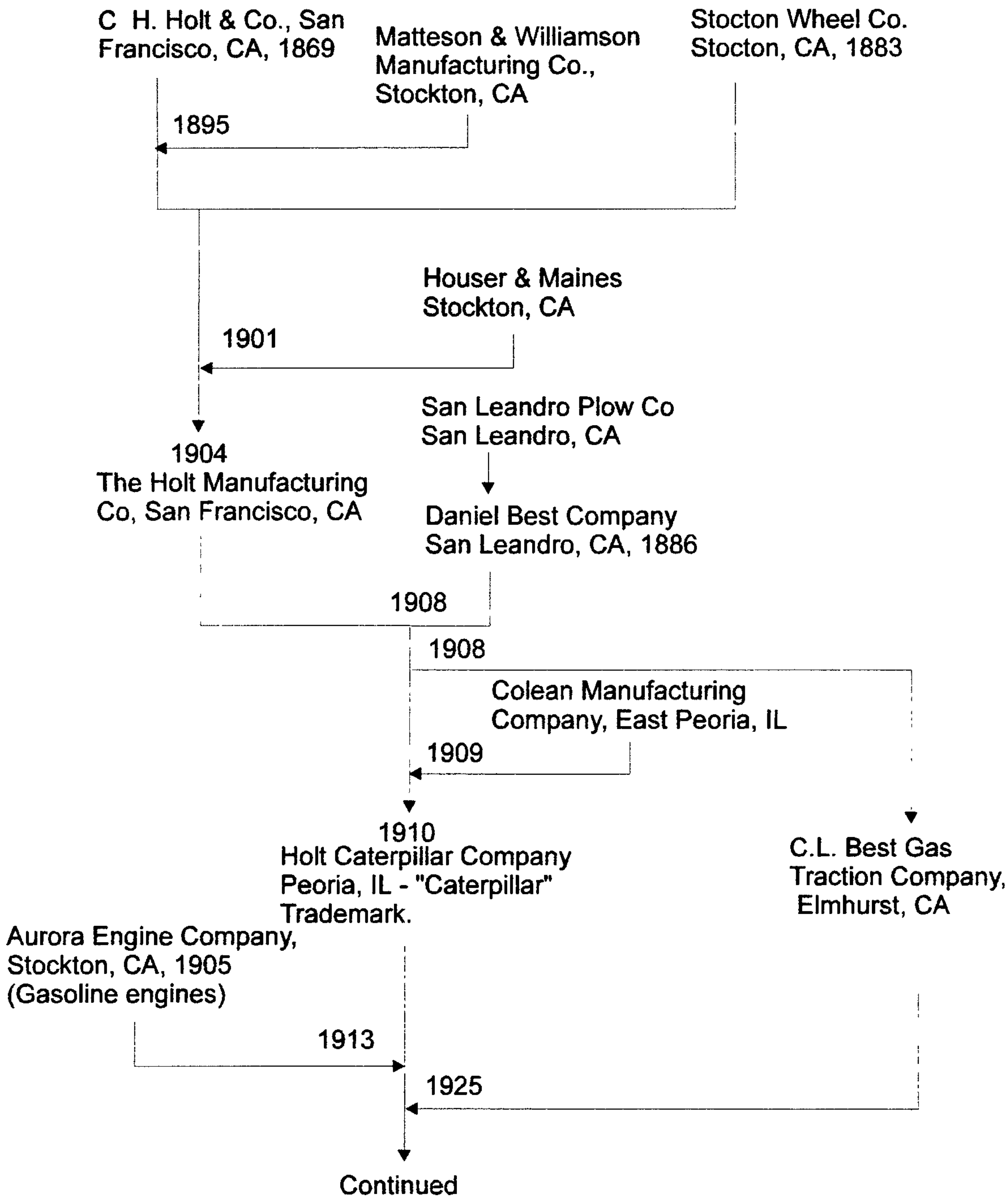
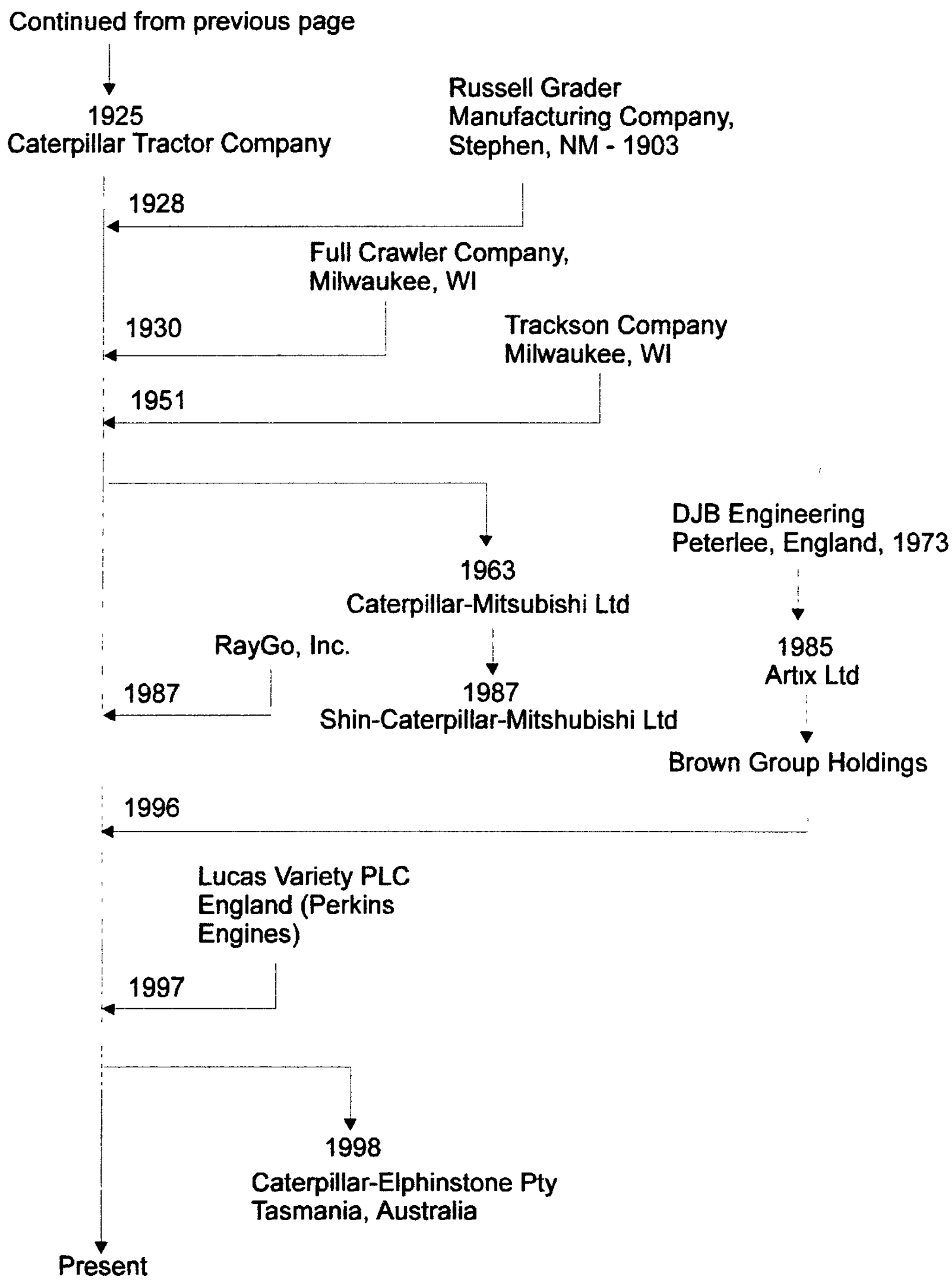
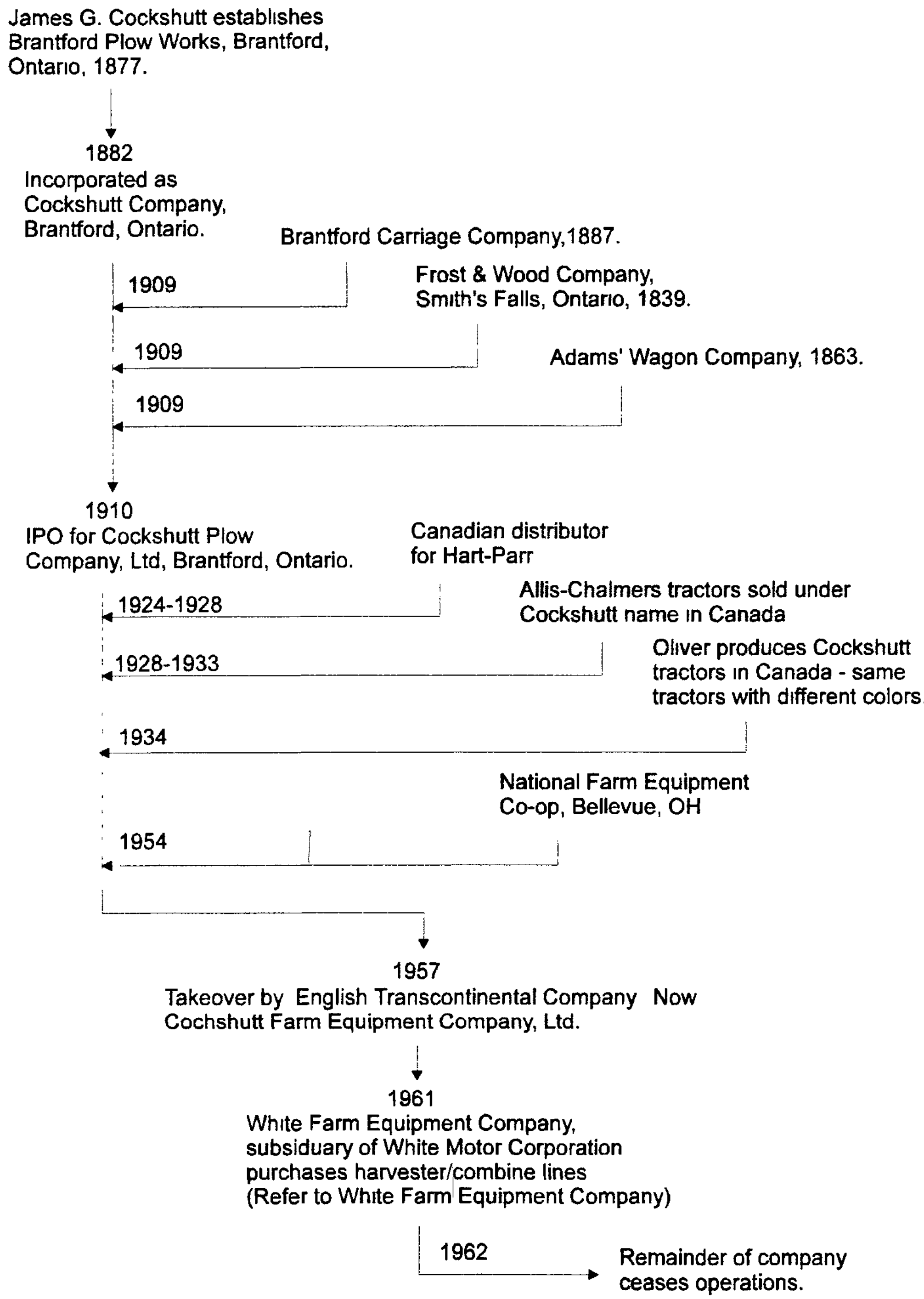


Figure 27. Caterpillar Tractor Company genealogy (Continued).



(Leffingwell 1994; Orlemann 1998; Sanders 1996)

Figure 27. Caterpillar Tractor Company genealogy.



(Cockshutt 1999; Cockshutt Models 1999; Cockshutt Shed 1999; Pripps 1994)

Figure 28. Cockshutt Farm Equipment Company, Ltd. genealogy.

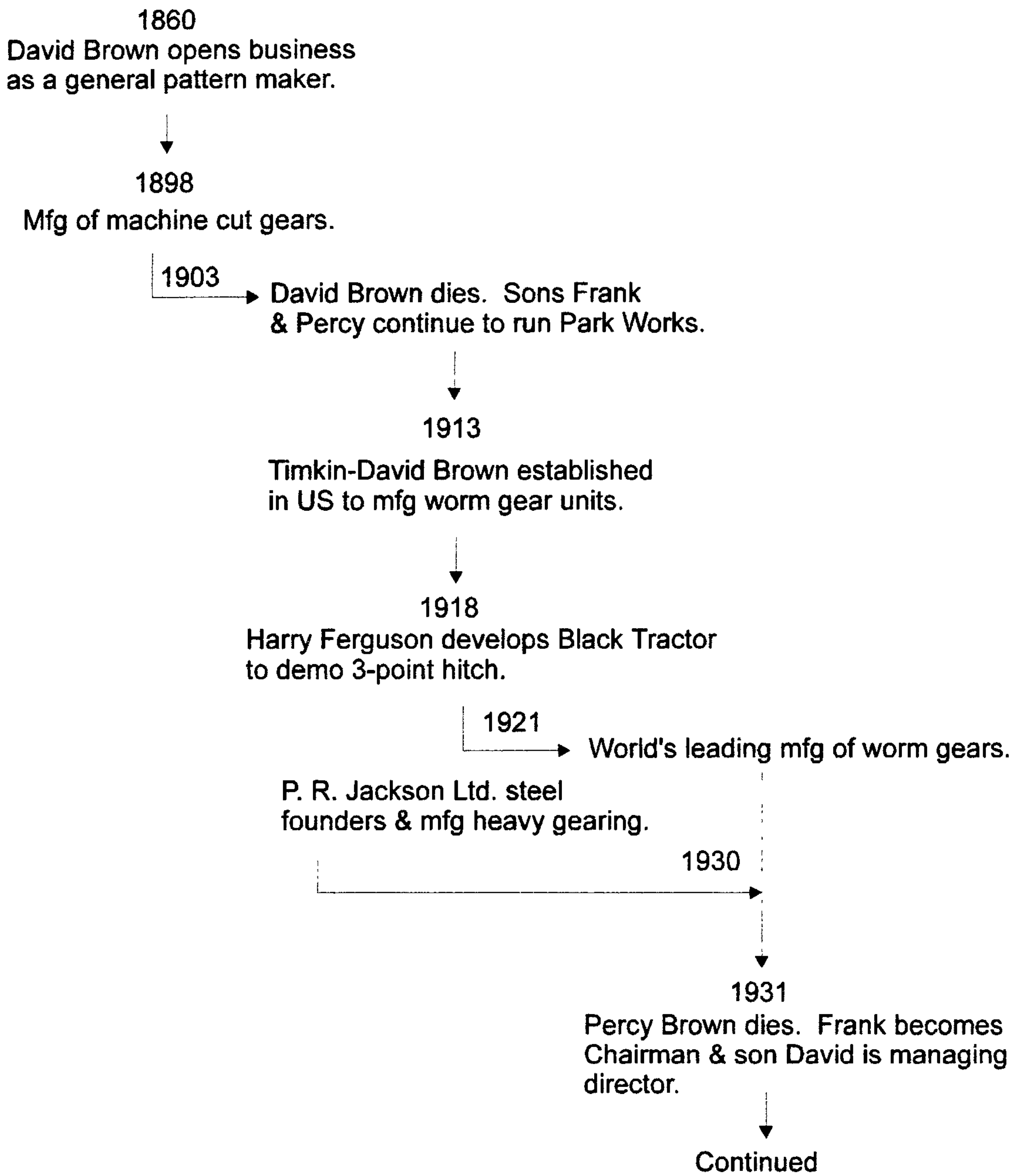
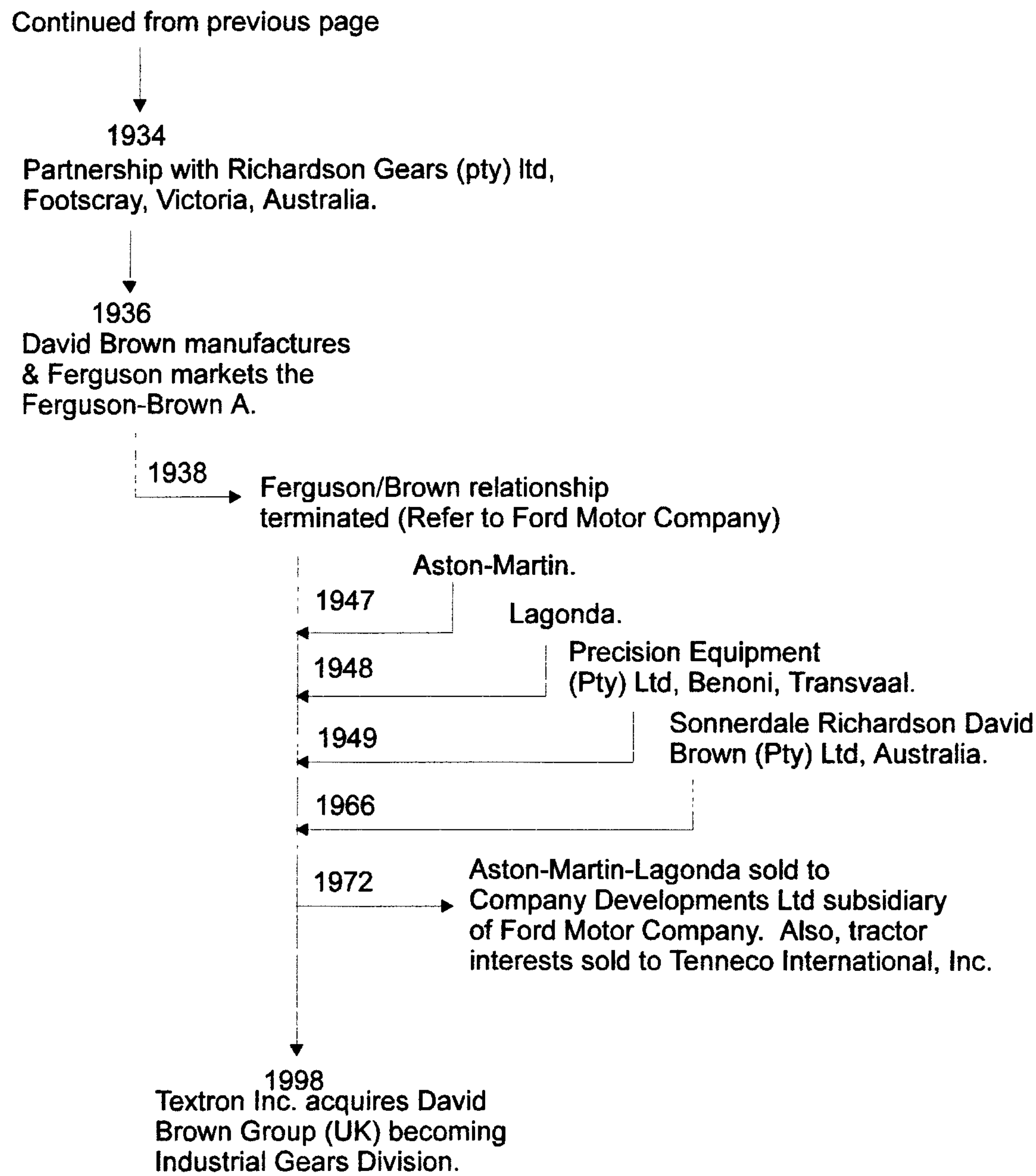
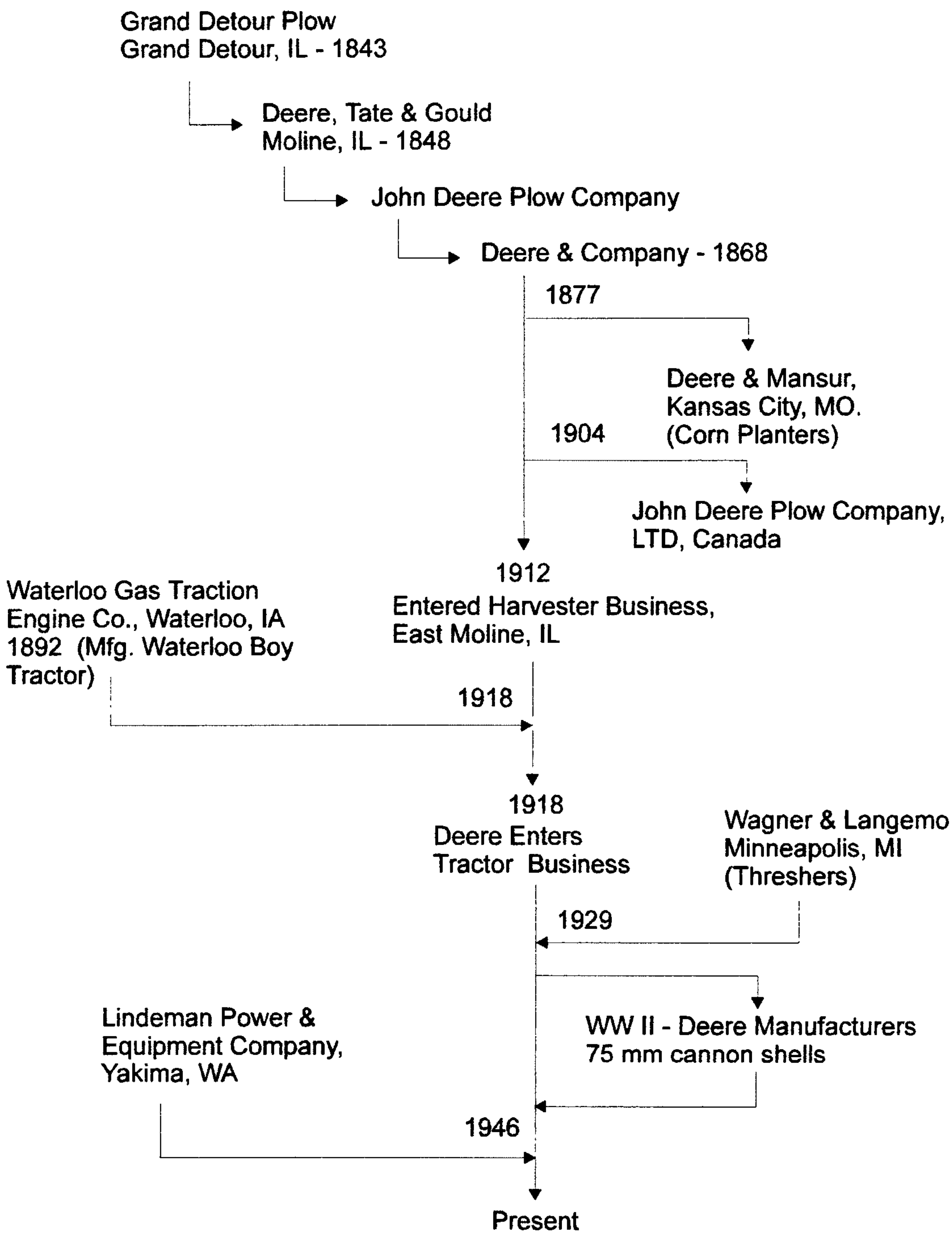


Figure 29. David Brown Tractors, Ltd. Genealogy (Continued).



(David Brown 1999)

Figure 29. David Brown Tractors Ltd. Genealogy.



(Pripps and Moreland 1998; Deere & Co. 1988; Deere & Co. 1994; Letourneau 1993; Sanders 1996; McMillan and Jones 1988)

Figure 30. Deere and Company genealogy.

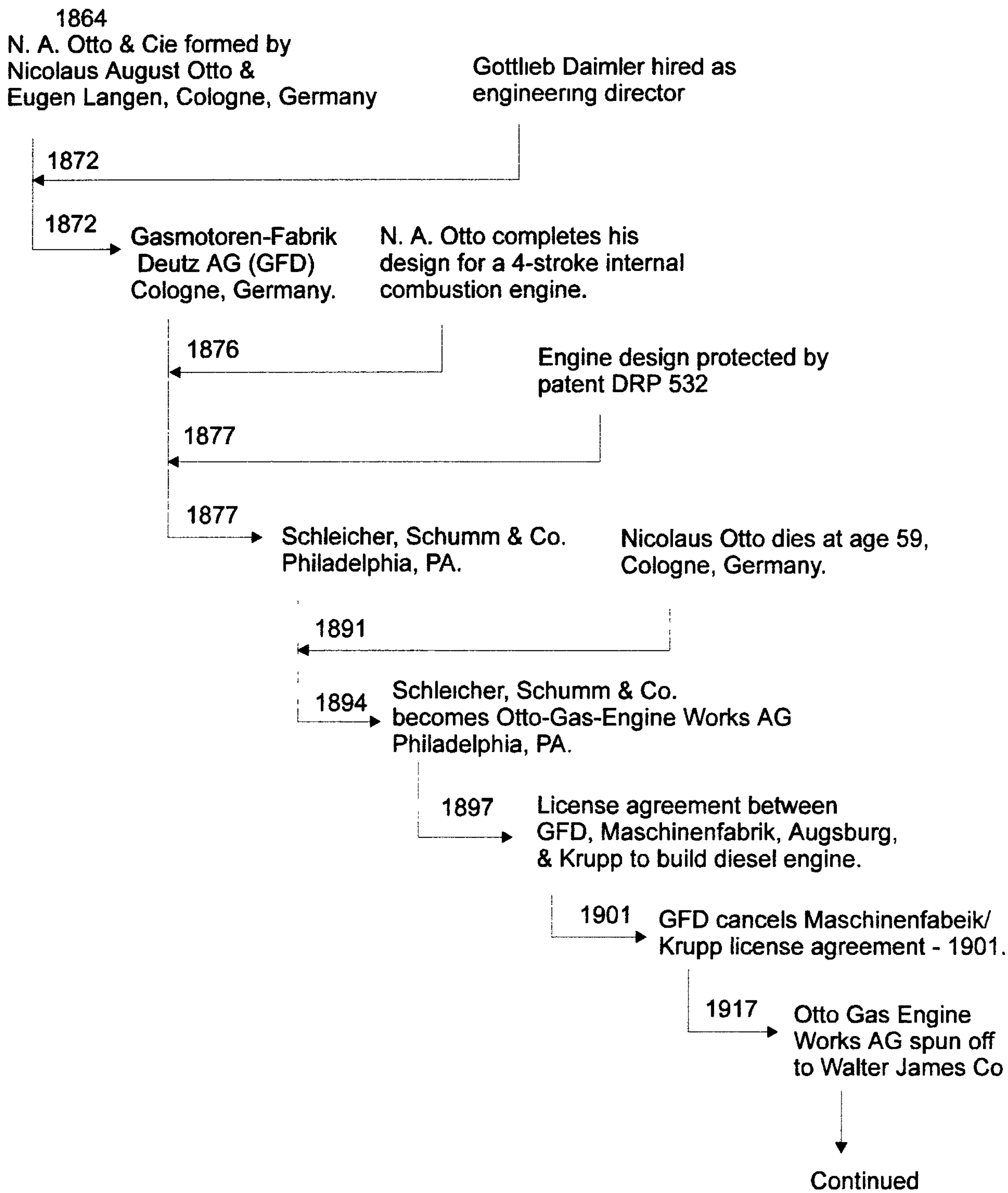
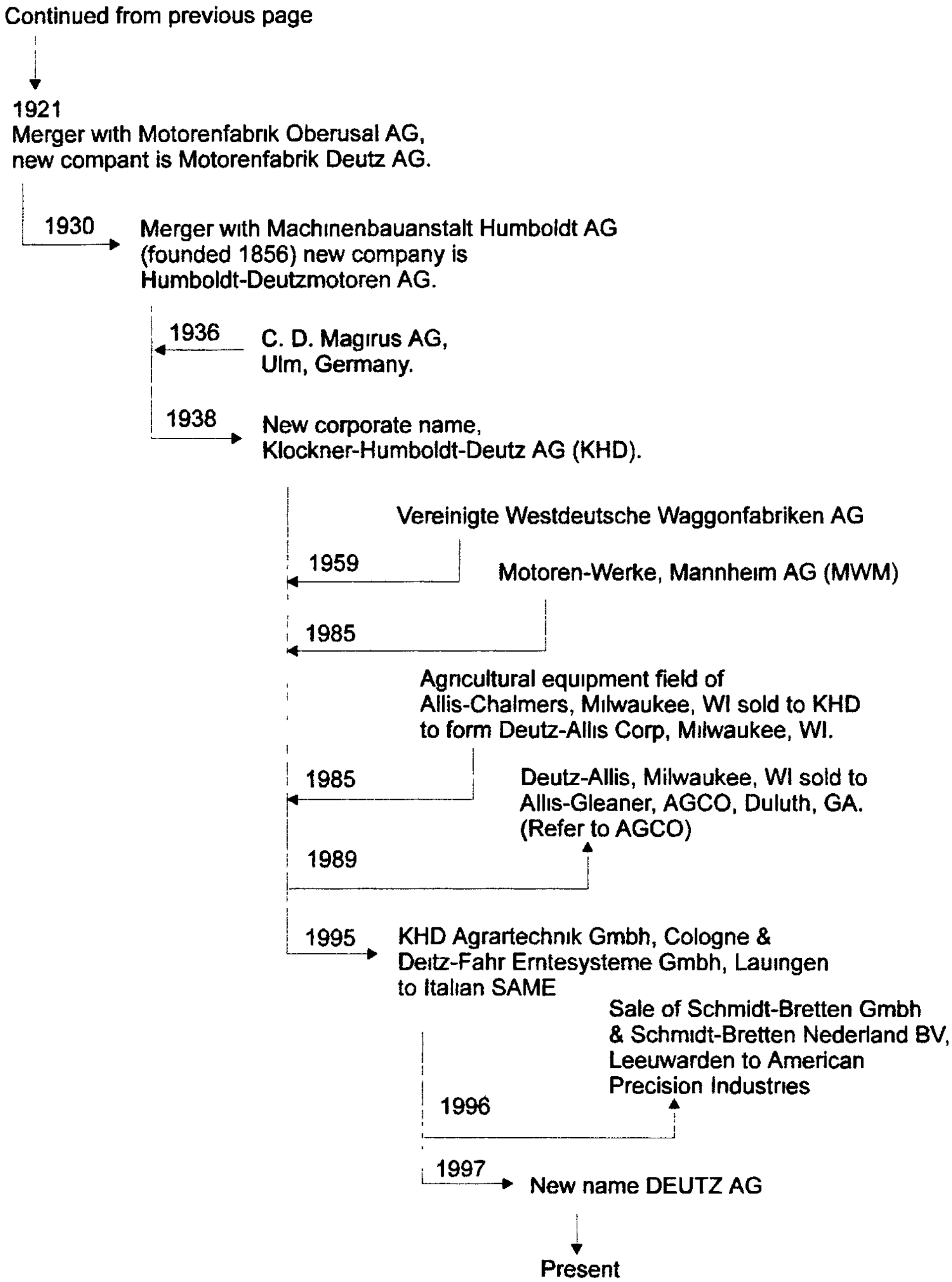
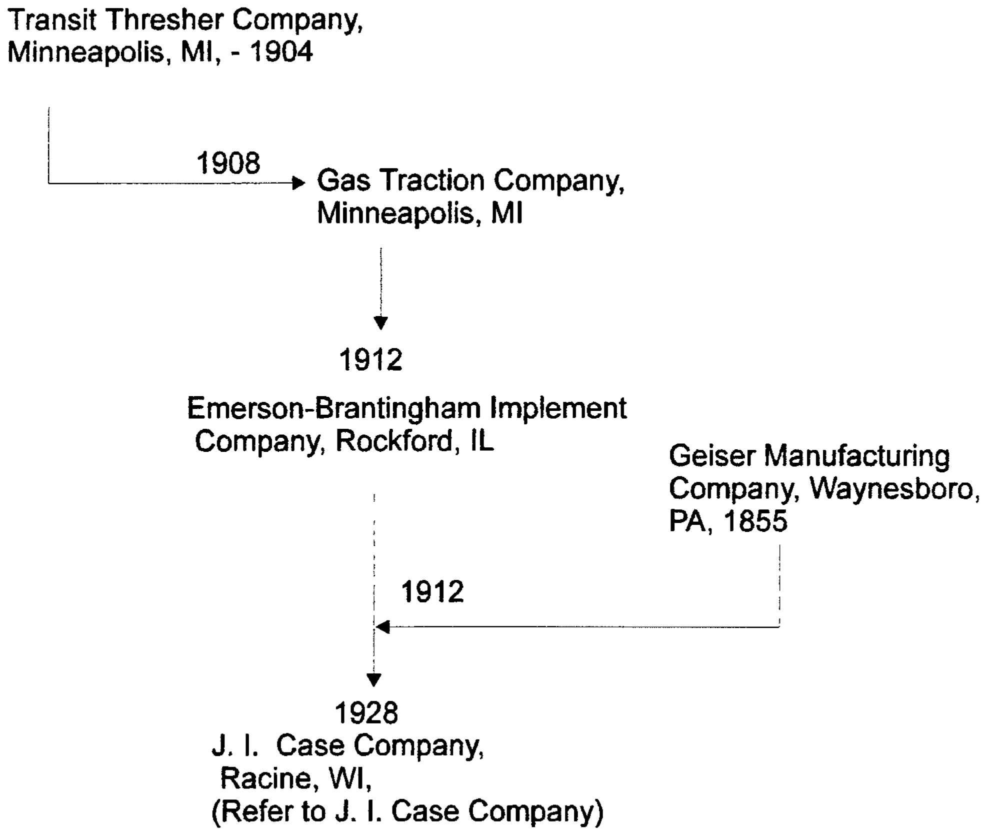


Figure 31. Deutz AG genealogy (Continued).



(Deutz 2001; Deutz History 2001)

Figure 31. Deutz AG genealogy.



(Sanders 1996; Steam 1999; Erb and Brumbaugh 1993)

Figure 32. Emerson-Brantingham Implement Company genealogy.

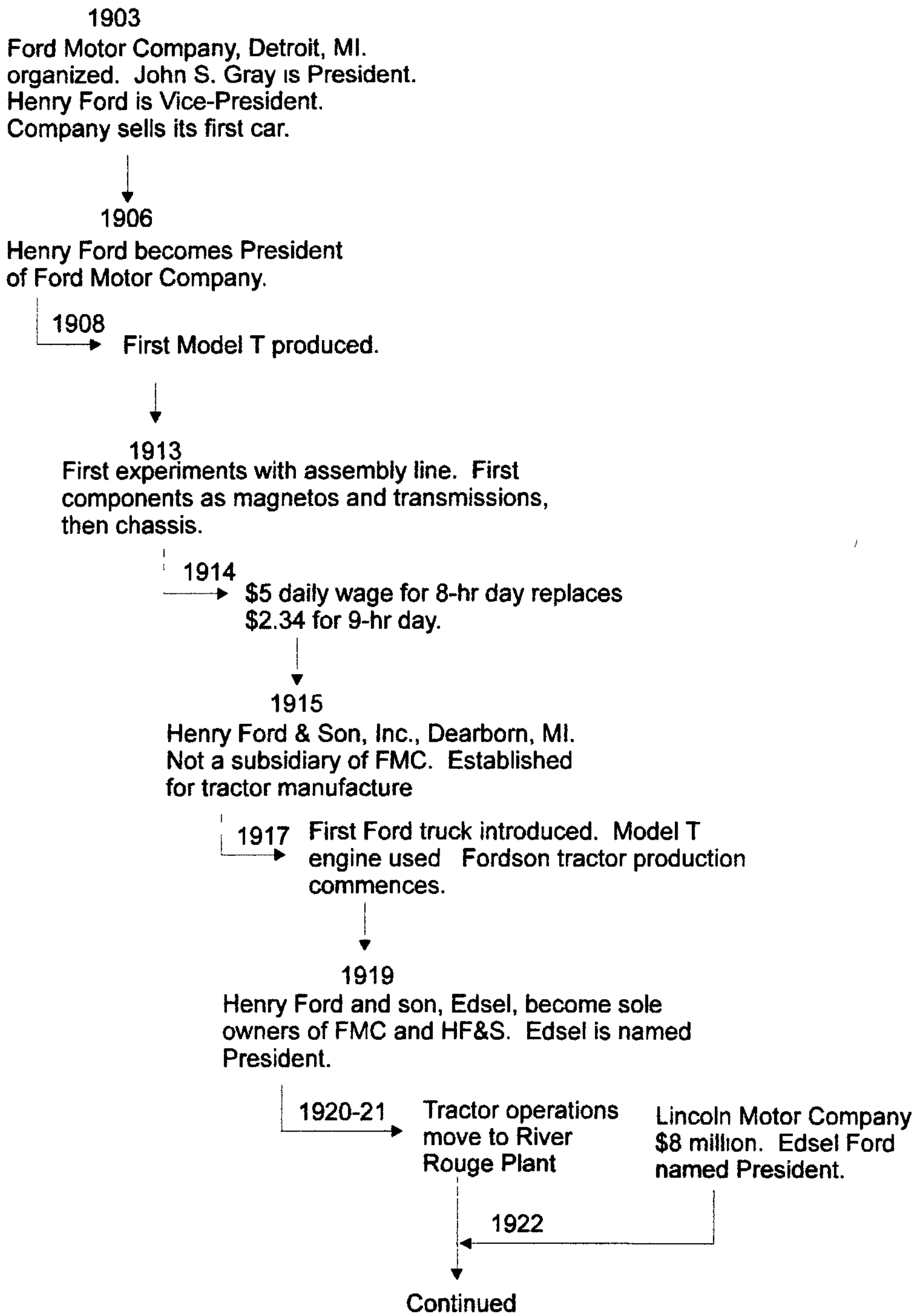


Figure 33. Ford Motor Company genealogy (Continued).

Continued from previous page

1925
Fordson production reaches 500,000.

1927
Model T production ceases w/ production run of 15,007,003 units. Model A production begins.

1928
All tractor operations moved to Cork at serial #757369

1932
Tractor production at Cork closed at serial #779135.

1932
Ford V8 '60' introduced.

1934-35
Tractor experiments resume in Dearborn.

1938
Harry Ferguson arrives from UK. "Handshake agreement" reached. Mercury production commences.

1939
Ford 9N tractor introduced with Ferguson System (3-point connection).

Continued

Figure 33. Ford Motor Company genealogy (Continued).

Continued from previous page

1943
Edsel Ford dies at age 49. Henry Ford re-elected President.

1945
Henry Ford II, son of Edsel, named President.

1947
Henry Ford dies at age 83.
Fordson production reaches 1.7 million.
8N tractor introduced.

1956
Ford Motor Company becomes publicy held with an IPO. Listed on NYSE.

1960
Henry Ford II resigns as President. Becomes Chairman and CEO.

1979
Henry Ford II retires as CEO. In 1980 retires as Chairman.

1985
Sperry New Holland. New Holland, PA. Name changed to Ford New Holland. Interest is harvester production.

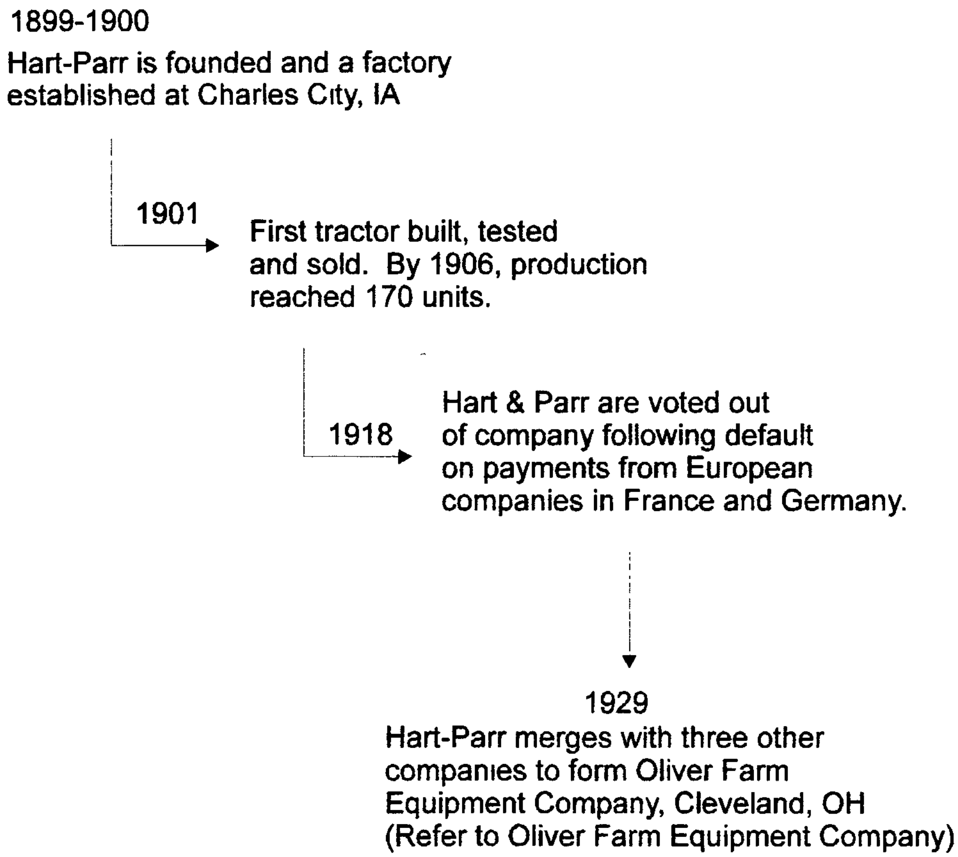
1987
Henry Ford II dies.

1990
Ford and Fiat merge tractor operations from Ford New Holland and Fiat GeoTech to form New Holland GeoTech (Fiat holds 80% of new company.

2000
Ford name replaced by New Holland on dealerships and tractors.

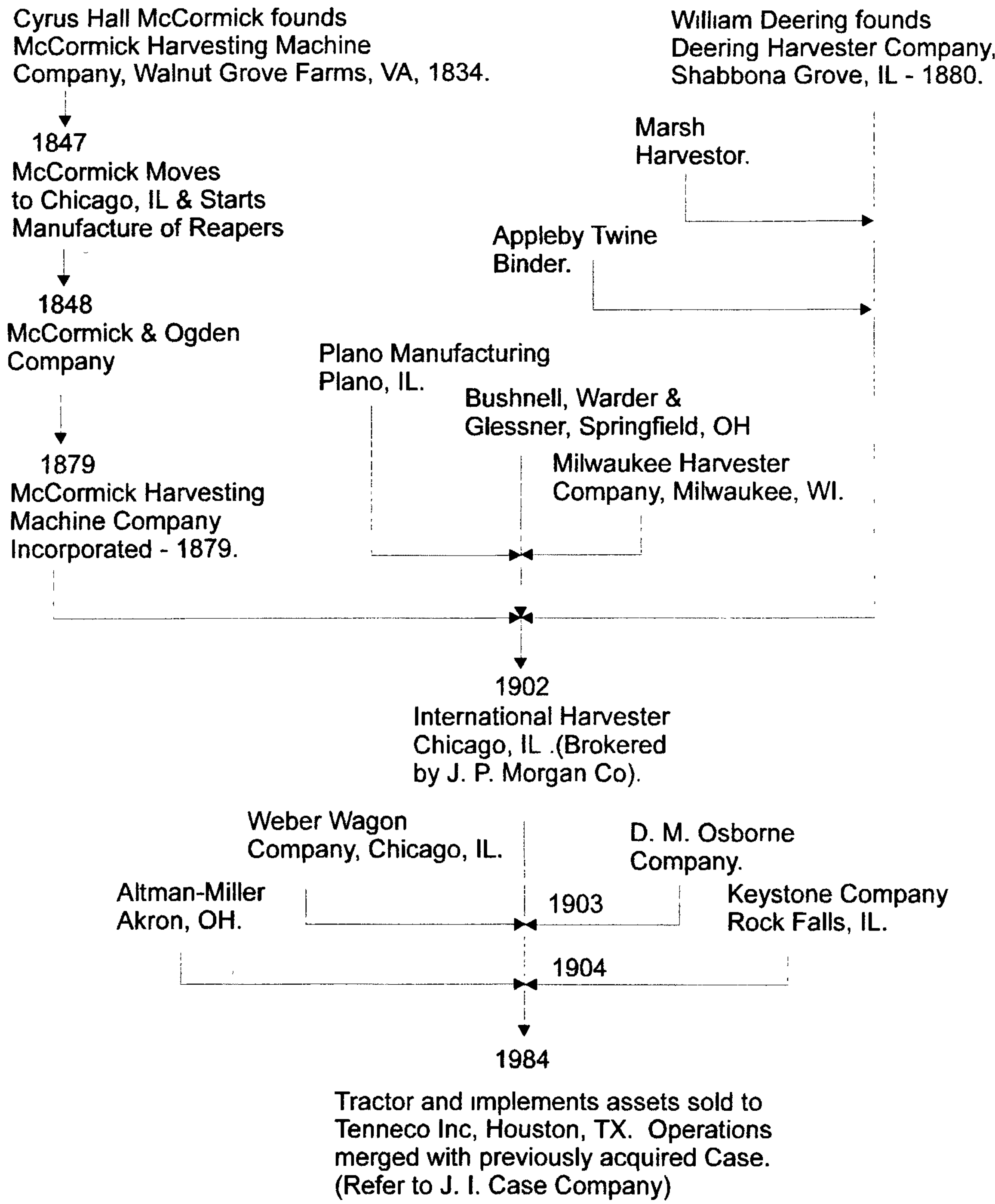
(Williams 1992b; Sanders 1996; Ford History 1999; Pripps and Morland 1992, 1997)

Figure 33. Ford Motor Company genealogy.



(Halberstadt 2000, Gray 1975)

Figure 34. Hart & Parr Company genealogy.



(Pripps and Moreland 1998; Fay and Kraushaar 1998; Klancher 1995; Gray 1975; Halberstadt 2000; Sanders 1996)

Figure 35. International Harvester Corporation genealogy.

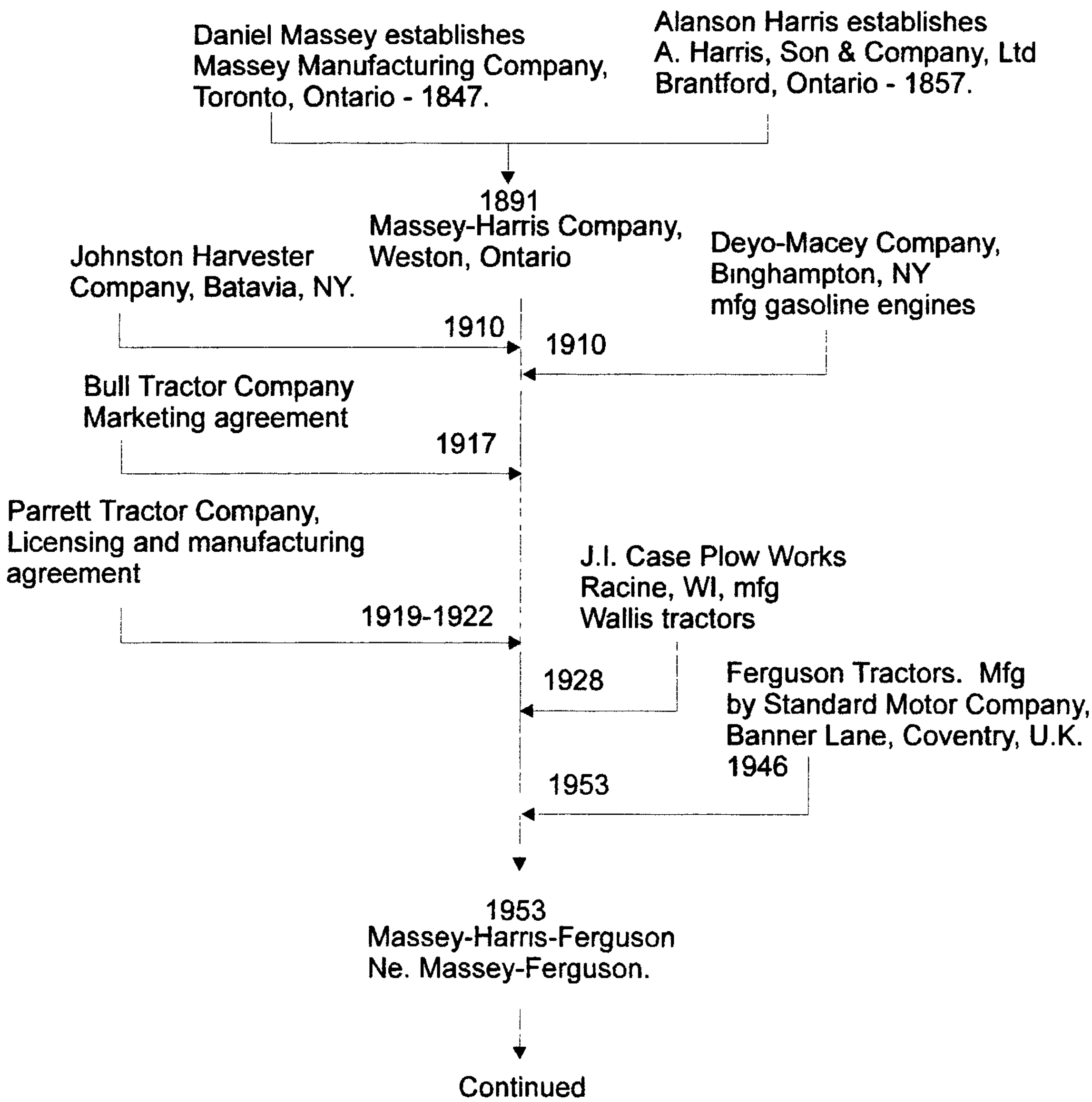
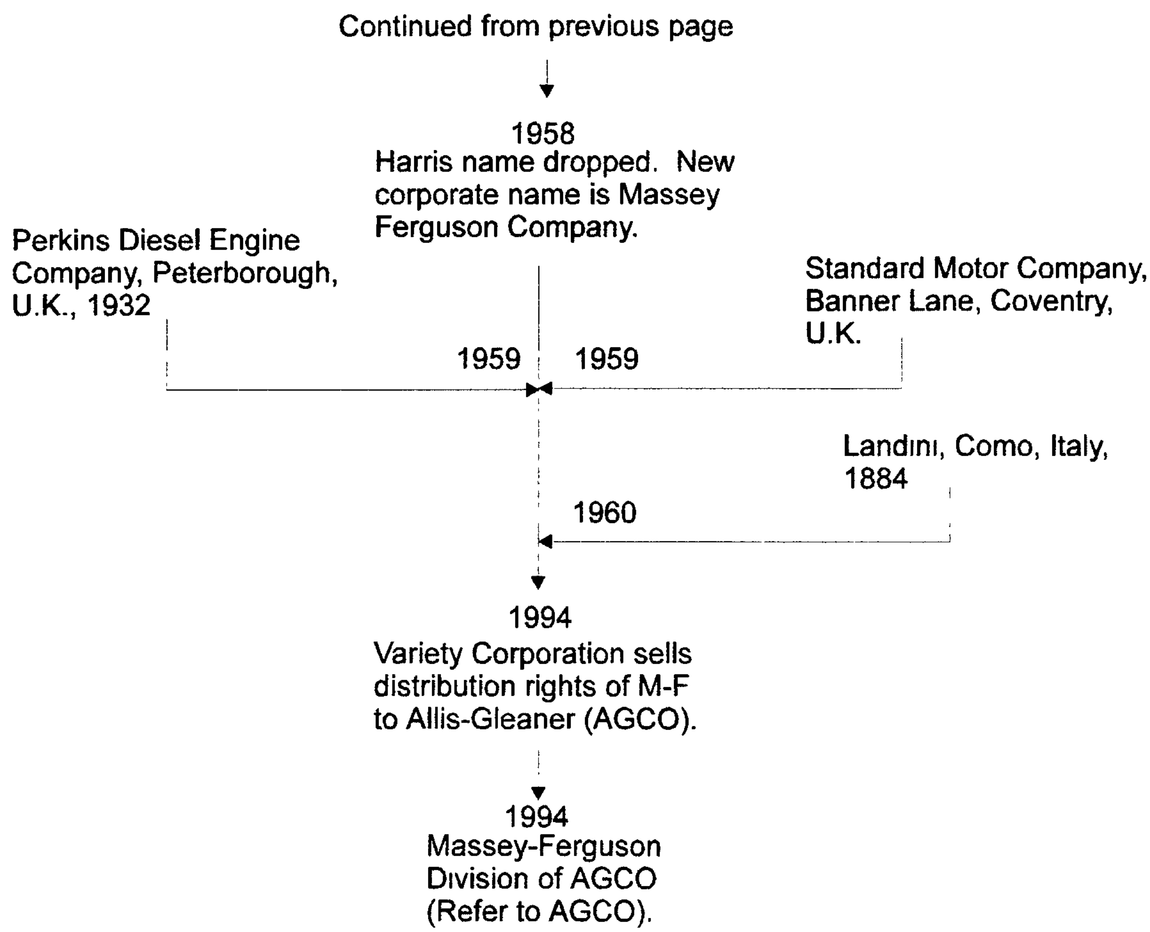
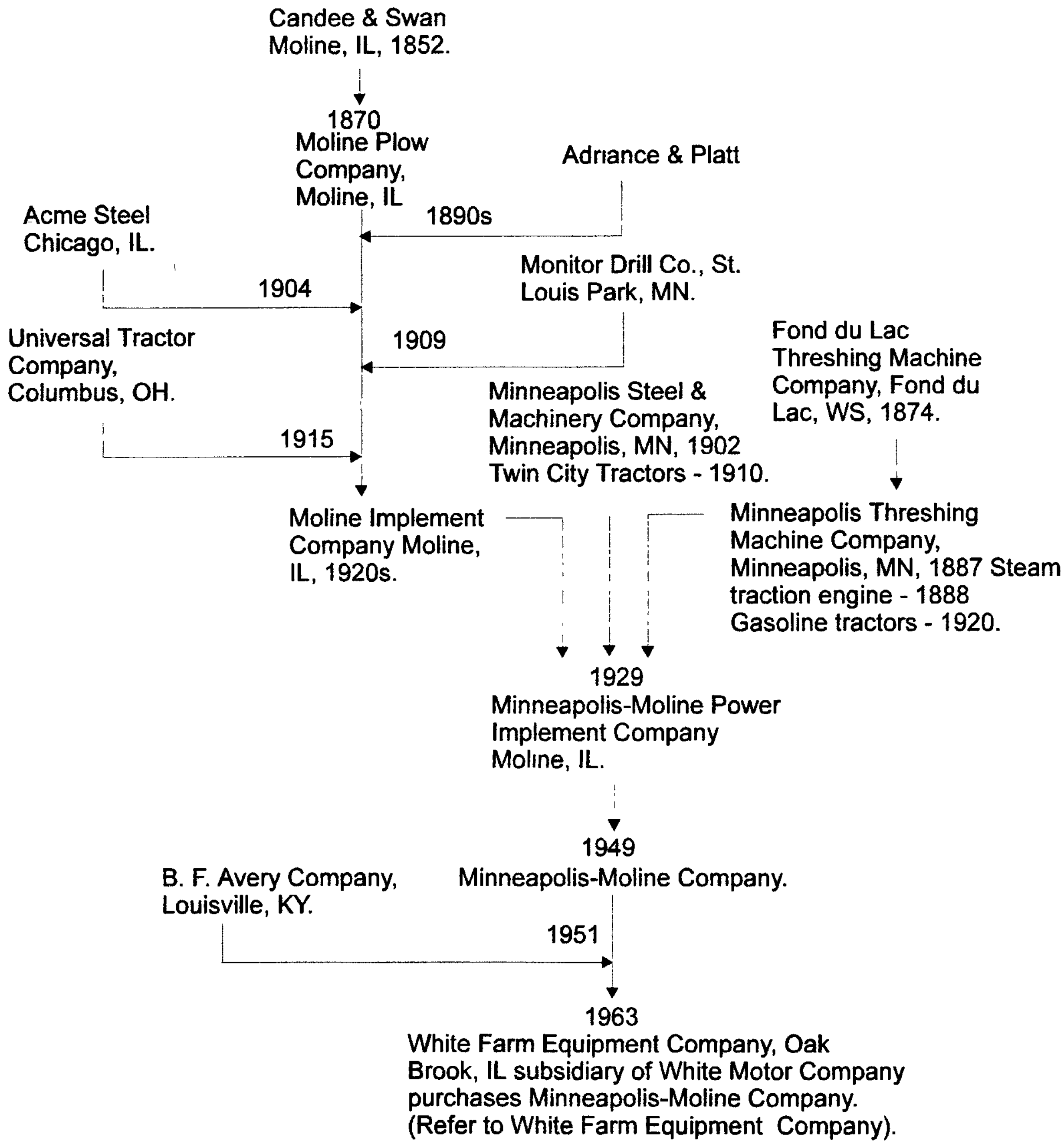


Figure 36. Massey-Harris-Ferguson genealogy (Continued).



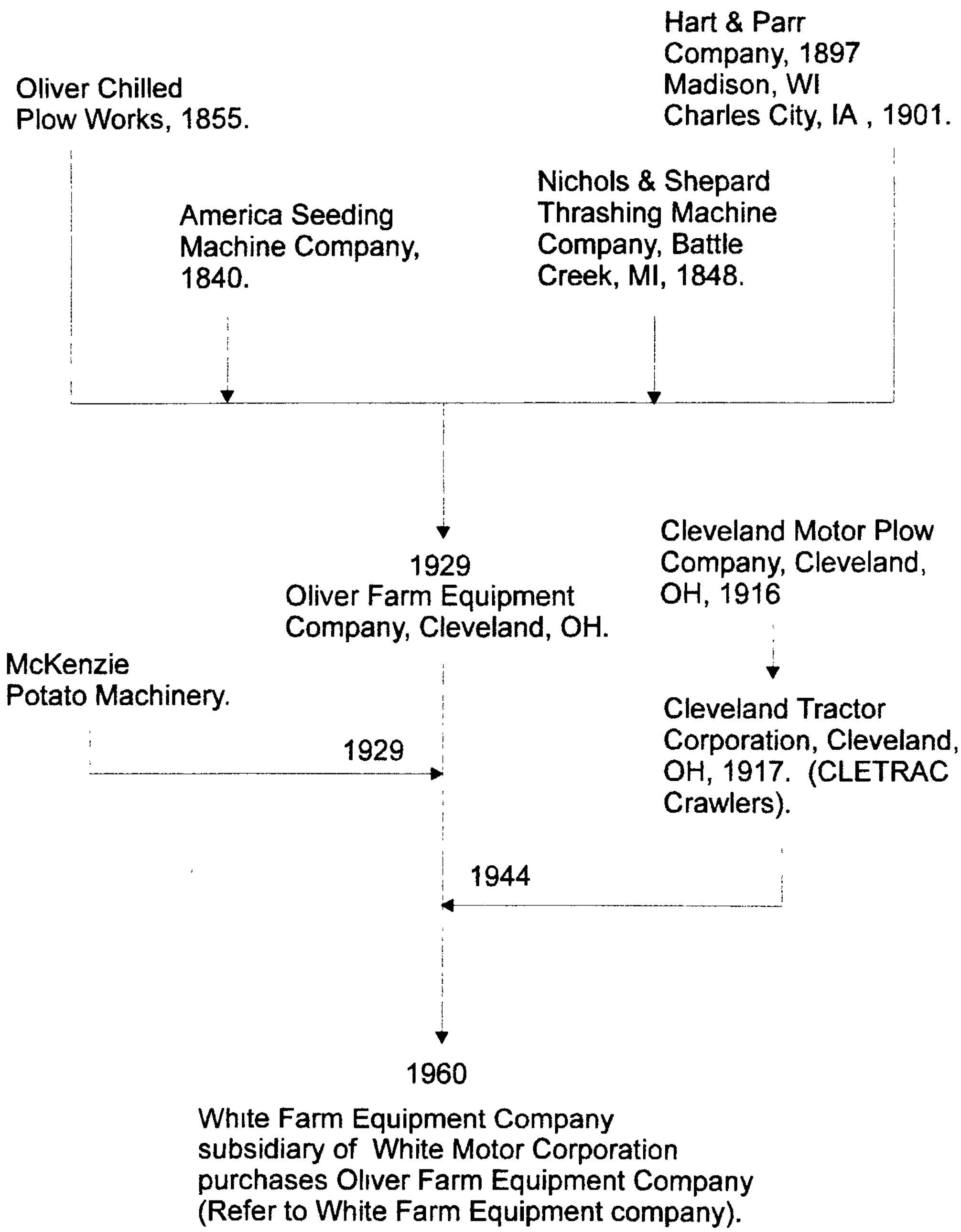
(Sanders 1996; Massey-Ferguson 1999; Harry Ferguson 1999; Williams 1992a; Wendel and Morland 1994)

Figure 36. Massey-Harris-Ferguson genealogy.



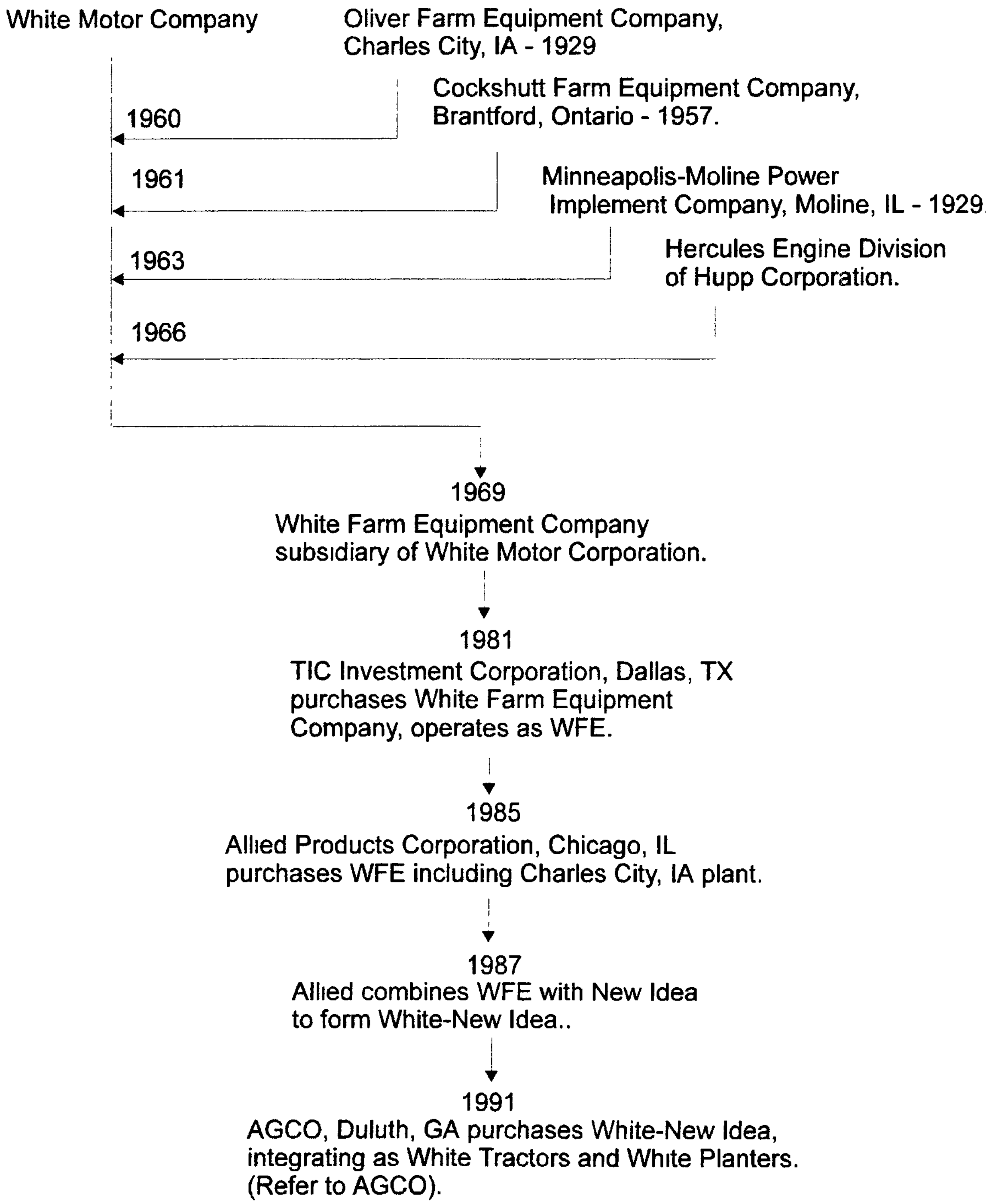
(Steam Engines and Tractors 1999; Sanders 1996; Cockshutt Shed 1999; Wendel and Morland 1990; Sayers 1996)

Figure 37. Minneapolis-Moline Company genealogy.



(Letourneau 1993; Sanders 1996; Morrill and Hackett 1996; Gay 1997; Gray 1975)

Figure 38. Oliver Farm Equipment Company genealogy.



(Sanders 1996; Gay 1997; Morrill and Hackett 1996)

Figure 39. White Motor Company genealogy.

APPENDIX B

TRACTOR MANUFACTURER MODELS

TABLE 29
ADVANCE-RUMELY THRESHER COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
E OilPull 30-60	1910	1923		1920	0008	49 91	27 91						26,000			Hvy Wt
F OilPull	1911	1918				35 00	18 00						16,000			Hvy Wt
H OilPull 16-30	1917	1924	13,040	1920	0009	30 50	16 68	2	2/1	2 10	3 00		9,500			Hvy Wt
G OilPull 20-40	1918	1924		1920	0011	46 00	30.00						11,000			Hvy Wt
K OilPull 12-20	1918	1924	7,284	1920	0010	26 00	15 00		2/1	2 1	3 26		6,638			Hvy Wt
L OilPull 15-25	1924	1927	4,855	1925	0112	30 52	18 48						6,050			Lt Wt
M OilPull 25-30	1924	1927	3,671	1925	0111	35 39	27 54						8,750			Lt Wt
R OilPull 20-45	1924	1927	768	1925	0116	50 57	27 42		3/1				11,900			Lt Wt
S OilPull 30-60	1924	1928	515	1924	0103	70 16	40 00	2	3/1	2 00	3 00		17,500			Lt Wt
W OilPull 20-30	1928	1930	3,953	1927	0141	35 36	24 89		3/1	2 20	3 50	Kero	6,776			Super Lt Wt
X OilPull 25-40	1928	1930	2,401	1927	0143	50 26	37 79	2	3/1			Kero	9,440			Super Lt Wt Oil cooled
Y OilPull	1929	1929	246			50 00	30 00						13,025			Super Lt Wt
Z	1929	1929	216			60 00	40 00						17,500			Super Lt Wt
B OilPull	1910	1912	937			45 00	25 00	2					23,800			Hvy Wt
DoAll	1928	1931	3,194	1928	0154	21 61	16 32	4		2 63	3 75		3,702		995	
Rumely 6 A	1930	1931	802	1931	0185	43 23	27 65	6	3/1	2 82	4 72	Gas	6,370			

(Rumely 1999; Wendel 1993; King 1989)

TABLE 30
ALLIS-CHALMERS MANUFACTURING COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
10-18	1914	1923				18 00	10 00	2				Gas/ Kero	4,800			3-Wheel
15-25 (Model L)	1920	19927	1708													Production includes 12-20
E20-35	1928	1929	10,435					4/461						1927	1,295	
Model A	1936	1942	1,225			51 20	39 70		4/1	9 0	10 0					
Model WF	1938	1951	8,350													
6-12	1918	1926	1,471	1920	0054	12 37	6 27	4/138	1/1	2 5			2,500			
15-30/18-30	1918	1921	1,160	1920	0055	33 41	20 55	4/461				Kero	6,000			
				1921	0083	43 73	25 45	4/461				Gas	6,640			
12-20	1920	1927	1,708	1921	0082	33 18	21 42	4/281				Gas	4,550			
20-35	1923	1928	3,840	1928	0151	44 29	33 20	4/461				Gas	7,095			
United & Model U	1929	1952	21,268	1929	0170	35 04	25 63	4/284	4/1			Gas	4,821			(s) – Steel tires
				1935	0237	34 12	23 83(s	4/284				Dist	5,030			(r) - Pneumatic tires
						34 02	)	4/284					5,140			
							30 07(r)									
E25-40	1930	1936	1,426	1931	0193	47 00	33 82									
All Crop & Model UC	1930	1941	7,217	1931	0189	36 09	24 98	4/284				Gas	5,965			
				1935	0238	34 09	24 17(s	4/301				Dist	5,710			
							)	4/301				Dist	6,115			
							28 85(r)									
WC	1933	1948	178,202	1934	0223	21 48	14 36(s	4/201				Dist	3,190	1934	625	Pneumatic tires add
							)	4/201				Dist	3,792			$150
				1938	0303	25 45	19 14(r)	4/201				Dist	3,175			
							18 72(s	4/201				Dist	4,545			
				1938	0304	29 93	)	4/201				Gas	3,165			
							19 17(r)	4/201				Gas	4,535			
							22 29(s									
							)									
							24 16(r)									
Model B & IB	1937	1958	126,211	1938	0302	15 68	12 97	4/116	4/116			Dist	2,620			
				1950	0439	22 25	19 51	4/116	4/125			Gas	4,193			
Model RC	1938	1941	5,501	1939	0316	18 21	15 25	4/125	4/1			Dist	4,005	1938	665	Add $120 for pneumatic tires

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
Model C	1940	1950	84,020	1940	0363	19 40	15 96	4/125	3/1			Dist	3,205			
				1940	0364	23 30	18 43	4/125				Gas	3,205			
Model G	1948	1955	29,970	1948	0398	10 33	9 04	4/62	3/1	1 60	7 00	Gas	1,749			Unique rear engine design Popular with small truck farmers
												Gas				
Model WD	1948	1953	146,125	1950	0440	34 63	30 23	4/201				Gas	6,313			
				1948	0399	26 14	24 31	4/201				Dist	5,042			
Model CA	1949	1958	39,509	1950	0453	25 96	22 97	4/125	4/1			Gas	3,557			
Model WD45	1953	1957	90,045	1953	0499	43 21	37 84	4/226	4/1	2 350	11 25	Gas	8,005			
				1953	0511	33 01	29 49	4/226	4/1			Fuel	7,185			
				1953	0512	44 13	38 53	4/226				LPG	8,065			
				1955	0563	43 29	39 50	6/230				Diesel	8,035			

(Swinford 1996; Wendel 1993; King 1989)

TABLE 31
B. F. AVERY COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
Model C				1920	0039		8 65	6	3/1	1 63	4 5	Gas	3,164			
12-20				1920	0041	24 26	17 58	4					5,500			
14-28				1920	0042	28 16	17 68	4	2/1	2 33	3 50	Kero	7,540			
25-50				1920	0043	56 68	31 50		2/1	2 00	3 00	Kero				
45-65				1920	0044	69 23	49 97	4	2/1	2 00	3 00		22,000			
18-36				1920	0058	44 50	27 50	4	2/1	2 80	4 00	Kero	9,250			
12-25				1921	0071	25 02	13 77	2					7,500			
8-16				1921	0072	16 66	9 99	2	2/1	2 25	3 50	Gas	4,900			
Track-Runner				1923	0089	30 60	20 13	4	3/1	2 43	3 90	Gas	5,600			Half track configuration
20-35				1923	0096	37 33	22 62	4	2/1	3 00	4 00	Kero	7,540			

(Wendel 1993)

TABLE 32
J. I. CASE CORPORATION MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
10/18				1920	0003	18 41	11 24	4	2/1	2 25	3 50	Kero	3,760			
15/27				1920	0004	31 23	18 80	4	2/1	2 25	3 00	Kero	6,460			
22/40				1920	0005	40 06	29 04	4	2/1	2 20	3 20	Kero	9,940			
10/20				1920	0006	20 00	15 28	4					5,080			
20/40				1920	0007	40 00	24 66	2	2/1	2 00	3 00		13,780			
12/20				1922	0088	20 17	13 15	4	2/1	2 20	3 00	Kero	4,450			
40/72				1923	0090	91 42	72 40					Kero	22,000			
12/20				1923	0091	20 16	17 52	4	2/1	2 20	3 00	Kero	4,450			
18/32				1924	0109	32 08	19 21					Kero	6,680			
L				1929	0155	44 01	26 28		3/1	2 50	4 00	Kero	5,307			
C				1929	0167	29 81	17 41		3/1	2 30	4 50	Kero	4,155			
CC				1929	0169	28 79	17 88	4	3/1	2 60	5 14	Kero	4,240			
RC				1936	0251	19 80	14 21	4	3/1	2 33	4 50	Gas	3,350			
R				1938	0308	20 52	19 23	4	3/1	2 33	4 50	Gas	4,140			
L				1938	0309	47 04	40 80	4	3/1	3 52	5 58	Dist	5,300r			r – rubber tires
								4	3/1	3 52	5 58		8,025s			s – steel tires
DC				1940	0340	37 28	33 06	4	3/1	2 50	5 00	Gas	7,010			
VC				1940	0348	24 48	18 55	4	4/1	2 65	10 03	Gas	4,290			
D				1940	0349	35 36	30 67	4	4/1	2 75	11 00	Dist	7,005			
SC				1941	0367	22 29	19 44	4	4/1	2 50	9 66	Dist	4,200			
VAC				1949	0430	17 92	15.63	4	4/1	2 32	8 40	Dist	3,199			

VAC	1949	0431	21 33	19 10	4	4/1	2 32	8 40	Gas	3,173
LA	1952	0480	58 68	51 68	4/403	4/1	2 50	10 00	Gas	7,515
LA	1952	0481	48 86	44 51	4/403	4/1	2 50	10 00	Dist	7,565
LA	1952	0482	59 60	51 73	4/403	4/1	2 50	10 00	LPG	7,631
SC	1953	0496	31 71	27 68	4	4/1	2 50	10 33	Gas	4,965
SC	1953	0497	24 97	23 25	4	4/1	2 50	10 33	Dist	5,005
500	1953	0508	63 81	47 82	6/377	4/1	2 69	10 10	Dsl	8,015

(Letourneau 1997; Erb and Brumbaugh 1993; Wendel 1993)

TABLE 33
CATERPILLAR TRACTOR COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
2-Ton (Formerly T-35)				1922	86	25 38	15 13	4	3	2 2	5 2		4,040			
Sixty				1924	105											Listed as C L Best
Thirty				1924	104	30 24		4	3	1 8	3 6	Gas				No 240 listed as C L
				1936	271	36 37	26 71	4	5	1 70	5 4	Dist	9,975			Best Nos 271 and 272
				1936	272	37 80	26 59	4				Gas	9,975			listed as Caterpillar
Twenty				1928	150	29 49	26 32	4								
Fifteen				1929	159	21 29	15 00	4	3	2 0	3 6		5,031			
Ten				1929	160	18 10	10 00	4	3	2 0	3 5	Gas	4,575			
15				1932	207	20 39	13 74	4	3	2 0	3 5	Gas	4,750			
20				1932	205	27 43						Gas				
25				1932	203	32 97						Gas				
35				1932	206	43 80						Gas				
50				1932	204	51 64	38 96	4	4	1 6	4 7	Gas				
65				1932	209	78 41	67 86	4	3	1 9	4 4	Gas	24,965			
Diesel				1932	208	77 08	74 73	4	3	2 1	4 7	Diesel	25,860			
70				1933	213	82 40	72 73	4	6	1 7	5 0	Gas	30,800			
Diesel Fifty				1933	214	55 66	52 61	4	4	1 6	4 7	Diesel				
				1935	240	61 04	42 32	4	4	1 6	4 7	Diesel	20,790			
				1935	241	65 01	48 71	4				Diesel				
Diesel Seventy-Five				1933	218	92 85	80 51	6	6	1 7	5 0	Diesel	32,050			
Diesel Thirty-Five				1933	217	44.72	30 58	3	4	1 7	4 6	Diesel	14,720			
R-2				1934	225	32 47	27 15	4	4	2 0	3 6	Gas	7,420			
				1939	320	28 95	23 84	4	5	1 7	5 1	Gas	6,835			
				1939	321	28 56	27 78					Dist				
R-3				1934	227	41 99						Gas				
R-5				1934	224	58 89						Gas				
Twenty-Two				1934	226	29 36						Dist				
				1934	228	30 71						Gas				
Diesel Forty				1935	242	56 05						Diesel				
				1935	243	48 60						Diesel				

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
Forty				1935	244							Gas				
				1935	245	56 42						Gas				
Diesel RD-7				1936	255	95 97						Diesel				
Diesel RD-7 (61 Bhp)				1936	253	68 24						Diesel				
Diesel RD-7 (69 Bhp)				1936	254	77 47						Diesel				
Diesel RD-8				1936	256	103 2						Diesel				
				1936	257	1						Diesel				
						118 2										
						9										
RD-4 (D-4)				1936	273	39 82						Diesel				
Diesel D-8				1938	314	109 6						Diesel				
						4										
D-2				1939	322	29 98						Diesel				
				1949	418	36 02						Diesel				
				1955	553	41 86						Diesel				
D-7				1940	358	89 10						Diesel				
D-8				1940	357	127 9		6	5/1	1 70	4 80	Diesel	26,208			
				1949	415	3	99 66					Diesel	36,915			
D-6				1941	374	78 03						Diesel				
				1949	416	76 90						Diesel				
				1955	555	92 52						Diesel				
D-4				1949	417	51 81						Diesel				
				1955	554	58 88						Diesel				

(Sanders 1996; Wendel 1993; Orlemann 1998)

TABLE 34
CLEVELAND TRACTOR CORPORATION

Crawler Models

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
E																
Model R	1916						10 00									
H, 12/20	1918															
80	1933											Diesel				
35	1934															Tread widths – 31 – 76 inches for row crops "Rubberband" tracks
HGR	1947															
W, 12-20	1920			1920	0045	20 00	15 5			1	4	Kero	3,300			
F, 9-16				1922	0085	19 61		4	1/1	1	3	Kero	1,920			
K, 15-25				1926	0119	28 44	23 42	4				Kero	4,775			
				1926	0120	30 15	24 53	4				Gas	4,775			
A, 30-45				1926	0125	48 62	38 00	6	2/1	2 40	4 75	Gas	7,223			
40, 40-55				1928	0149	63 00	55 50	6	3/1	2 00	5 50		12,038			
60-80				1930	0182	90 23	83 53		3/1	1 75	3 60	Gas	22,840			
40-30				1931	0195	45 64	30 44		3/1	2 06	4 42		9,700			
15				1931	0196	25 83	18 69	4	3/1	1 95	4 37		5,700			
				1932	0202	26 94	17 75	4				Gas				
25				1932	0201	30 27	23 07	6	3/1	1 95	4 00					
40, Diesel DD				1935	0235	57 55	45 89		3/1	1 80	4 30	Diesel	12,150			
CG				1936	0258	50 07	46 03	6	3/1	1 87	4 44		11,800			
				1937	0289	52 60	47 28	6	3/1	1 87	4 44		11,700			
BG				1936	0259	38 42	27 20		3/1	1 8	3 50		8,686			
AG				1936	0260	27 89	19 40	4	3/1	1 75	3 75		7,025			
E				1936	0261	19 01	16 48	4	3/1	2 16	4 00					
FG				1936	0262	94 54	87 02	6	3/1	1 75	4 33		26,670			
FD				1936	0263	91 55	86 18	6	3/1	1 75	4 25		27,370			
				1939	0326	107 2 5	91 16	6	4/1	1 61	5 00		30,030			

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
BD				1937	0288	37 65	26 86	6	3/1	1 80	3 50		9,200			
				1939	0325	40 67	28 83	6	3/1	1 81	3 46		9,500			
General CG				1939	0323	19 29	14 26	4	3/1	2 25	6 00			1939	595	Wheeled tractor
HG	1939			1939	0324	17 59	11 14		3/1	2 00	5 00					Adjustable tread for row crops

Total of 40 CLETRAC models made from 1917 to 1944 when sold to Oliver.

(Sanders 1996; Wendel 1993)

TABLE 35
COCKSHUTT FARM EQUIPMENT COMPANY LTD MODELS

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
18-28 (Oliver Mfg)	1930	1937														
28-44 (Oliver Mfg)	1930	1937														
60 RC (Oliver Mfg.)	1940	1948														
60 STD	1942	1948														
60 I	1946	1948														
70 RC (Oliver Mfg)	1935	1948														
70 STD	1936	1948														
70 I	1936	1948														
80 RC (Oliver Mfg)	1937	1948														
80 STD	1937	1948														
80 I	1932	1947														
90 (Oliver Mfg)	1937	1957														
99 (Oliver Mfg)	1937	1957														
99 I	1932	1947														
2	1954	1956														
3	1953	1955														
Model 30	1946	1956	37,328	1947	0382	30 28	21 68	4	4/1	2 50	10 00		3,609			
Model 40	1949	1957	14,92	1950	0442	41 44	30 36	6/230	6/1	1 60	12 00	Gas	5,305			
Model 20	1952	1958	4,000	1952	0474	25 94	20 24	4/140	4/1	2 50	13 25	Gas	2,813			
Model 50				1947	0488	44 45	35 74	6/273	6/1	1 52	9 85	Diesel	6,163			
	1953	1957	3,974	1952	0487	52 18	38 78	6/273	6/1	1 52	9 85	Gas	6,163			

The Model 30, test number 0382 was the first Canadian tractor tested at the Nebraska Testing Laboratory.

(Cockshutt Models 1999; Cockshutt shed 1999; Wendel 1993)

TABLE 36
DEERE & COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
AW								2					3,997	1936	1,000	Wide front
														1939	1,130	
														1947	1,848	
														1951	2,504	
AOS								2					4,093			Streamlined AO
AN								2					3,697	1936	945	1-Wheel narrow front
														1939	1,065	
														1947	1,735	
														1951	2,370	
BN								2				Fuel	2,763	1936	675	Narrow front
														1939	797	
														1947	1,471	
														1951	1,920	
BW								2				Fuel	3,051	1936	748	Wide front
														1939	867	
														1947	1,593	
														1951	2,069	
GP-Tricycle	1928	1929	23					2/312								2-Wheel tricycle front end
GP Wide Tread	1929	1933						2/312						1932	850	Wide tread
GP WT Series P	1930							2/312	3/1	2 25	4 125	Kero				Wide tread – narrowed rear tread for potato rows
GPO	1931	1935	725					2/339	3/1	2 25	4 125	Kero				Orchard
BR	1935	1947						2				Fuel	2,889			Promoted as 1 plow
AO	1936	1953						2					4,088			Orchard version
ANH	1936	1947						2								High crop version of AN
AWH	1936	1947														High crop version of AW
AH	1950	1952														Later high crop version
AI																Industrial version
BO	1936	1947						2				Fuel	2,941			
BNH	1937	1946						2								

Model	Prod From	To	Units	Neb Year	HP #	Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
BWH	1937	1946						2								
BO Lindeman	1939	1947	2,000					2								Crawler by Lindemann
GN	1947							2				Fuel	5,694	1947	1,909	Narrow front
														1953	2,430	
GW	1947							2						1947	1,970	Wide front
														1953	2,950	
GH	1950							2						1953	3,180	High
Model D	1924	1953		1924	0102	27 00	15 00	2/465	2/1	2 45	3.27	Kero				Successor to Waterloo
				1926	0146	27 00	15 00	2/465	2/1	2 50	3 25	Fuell				Boy
				1935	0236	37 37	24 02	2/501	3/1	2 50	5 00	Fuel				First WB to bear Deere
				1940	0350	38 11	30 46	3/501	3/1	3 00	5 25	Fuel	8,125			name
D	1924	1953	160,000	1924	0102	27 00	15 00	2/465	2/1	2 45	3 27	Kero	4,100	1925	1,000	
				1926	0146	27 00	15 00	2/465	2/1	2 50	3 25		4,100			
				1935	0236	37 37	24 02	2/501	3/1	2 50	5 00	Dist	5,690			
				1940	0350	38 11	30 46	2/501	3/1	3 00	5 25	Dist	8,125			
GP	1928	1935	30,535	1928	0153	20 20	10 20	2/312	3/1	2 25	400	Kero	3,600	1931	1,200	Standard-front
				1931	0190	24 30	15 52	2	3/1	2 25	4 16	Dist	4,925	1932	825	
														1935	925	
A	1934	1952	300,000	1934	0222	23 52	16 22	2/309	4/1	2 50	6 25	Dist	3,525	1935	945	2-Wheel tricycle-front
A				1939	0335	26 32	20 12	2/309	4/1	2 33	5 25	Dist		1939	1,050	
AR	1935	1952		1941	0378	26 30	20 35	2/247	4/1	2 00	6 50		4,815	1947	1,653	
A				1947	0384	33 53	26 48	2/321	6/1	2 50	13 0	Gas	5,228	1951	2,297	
AR				1949	0429	33 24	26 16	2/321	6/1	1 25	11 00	Gas	5,594			
B	1935	1952	300,000	1935	0232	14 30	9 38	2/149	4/1	2 25	6 75	Gas	2,731	1935	650	
				1938	0305	16 86	10 76	2/175	6/1					1939	787	
				1941	0366	17 46	14 08	2	6/1	2 33	12 25	Dist		1947	1,406	
				1947	0380	24 39	19 13	2/190	6/1	1 50	10 00	Gas		1951	1,870	
				1947	0381	20 68	16 64	2/190	6/1	1 50	10 00	Fuel				
														1952	1,900	
G	1938	1953	64,000	1937	0295	31 44	20 70	2/412	4/1	2 25	6 00	Fuel	4,400	1938	1,125	Total of 63,000 units (all
				1947	0383	33 83	27 01	2	6/1	2 50	12 50	Fuel		1939	1,085	Mod G's)
														1947	1,879	
														1953	2,132	
L – Utility Tractor	1937	1946	13,365	1938	0313	9 27	7 01	2/66	3/1	2 50	6 00	Gas	2,180	1946	517	
LA – Utility Tractor	1941	1946		1941	0373	12 93	10 46	2/77	3/1	2 50	9 00	Gas	2,285			
H	1939	1947	60,000	1938	0312	12 97	9 68	2/100	3/1	2 50	5 75	Fuel	2,141	1940	650	2-Wheel, narrow front
HN	1940	1947											2,131			
HNH	1941	1947														
HWH		1947														
M	1947	1952	45,799	1947	0387	18 21	14 39	2/101	4/1	1 62	10 00		2,695	1952	1,075	
MT	1949	1952	30,472	1949	0423	18 33	14 08	2/101	4/1	1 75	11 00		2,550	1952	1,200	Tri-cycle M

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
R	1949	1954	21,293	1949	0406	43 32	34 27	2/415	5/1	2 12	11 50	Diesel		1954	3,650	
MC	1949	1952	10,509	1950	0448	18 89	13 70	2/101	4/1	0 90	4 70	Diesel	3,875			Crawler
50	1952	1956		1952	0486	26 32	20 62	2/190	6/1	1 50	10 00	Gas	4,855			
				1953	0507	21 89	17 42	2/190				Fuel				
60	1952	1956		1952	0472	35 33	27 71	2/321	6/1	1 50	11 00	Gas	5,911			
				1953	0490	28 27	22 57	2/321	6/1	1 50	11 00	Fuel	5,950			
70	1953	1956		1953	0493	42 80	33 16	2/379	6/1	2 50	12 50	Gas	6,617			
				1953	0506	38 22	30 75	2/413	6/1	2 50	12 50	Fuel	6,655			
				1953	0514	44 17	34 58	2/379				LPG				
				1954	0528	43 77	34 25	2/379	6/1	2 50	12 50	Diesel				
40	1953	1955		1953	0503	21 45	17 16	2/101	4/1	1 65	12 00					Standard & tri-cycle
40S				1953	0504	21 13	16 77	2/101					2,925			versions
40C				1953	0505	21 24	15 11	2/101	4/1	0 82	5 31		4,669			
40S				1955	0546	17 76	14 25	2/101	4/1	1 63	12 00	Fuel	3,007			Crawler

(Deere 1996a; Deere 1996b; Wendel 1993; Johnny Popper 2001; Brunswick 2001)

TABLE 37
FERGUSON MODELS

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
TE-20	1948	1951	25,000	1948	0392	24 02	16 35	4	4/1	2 90	11 49	Gas	2,760			
TO-30	1951	1954		1951	0466	27 96	19 26	4	4/1	2 90	11 48	Gas	2,843			
TO-35	1954	1960		1955	0564	29 29	23 67	4/134	6/1	1 23	13 49	Gas				
40	1956	1957		1956	0596	31 14	24 31	4/134	6/1	1 22	14 59	Gas	3,432			

(Wendel 1993; Massey-Ferguson 1999; Williams 1992a)

TABLE 38
FORD MOTOR COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
Fordson	1918	1928	750,000	1920	0018	18 16	9 34	4/251	3/1	1 34	6 83	Kero	2,710	1918	795	
				1926	0124	22 28	12 33					Kero	3,175	1922	395	
Fordson F				1930	0174	29 09	15 52	4	3/1	1 55	7 75	Gas				
				1930	0173	23 24	10 67	4	3/1	2 12		Kero	3,820			
Fordson All-Around				1937	0282	20 31	11 88	4	3/1	1 92	5 13	Dist	5,030			
				1938	0299	27 69	15 05	4	3/1	1 92	5 13	Gas	3,965			
Ford-Ferguson 9 N	1939	1943		1940	0339	23 07	12 48	4	3/1	2 51	7 48	Gas	3,375			
and 2 N	1942	1947														
8 N	1948	1952		1947	0385	18 35	13 62	4	4/1	2 75	10 16	Gas	2,714			
				1948	0393	25 77	17 43	4	4/1	2 97	10 97	Gas	2,600			
				1950	0443	23 24	17 65	4/120	4/1	3 23	11 92	Gas	2,717			
8 NAN				1950	0444	21 51	14 96	4/120	4/1	3 23	11 92	Dist	2,717			
NAA (Jubilee)	1953	1954		1953	0494	30 15	20 21	4/134	4/1	3 13	11 55		2,841			
Fordson Major				1953	0501	33 56	23 91	4/199	5/1	2 07	13 16	Gas				
				1953	0500	34 60	27 74	4/220	6/1	2 07	13 16	Diesel	5,308			

(Wendel 1993; Pripps and Morland 1997; Williams 1992b)

TABLE 39
HART & PARR COMPANY MODELS

Old Hart & Parr Models

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
No 1	1901	1902	1			30 00	17 00	2								
No 2	1902	1906	1			45 00	22 00									
No 3 or 17-30	1903	1906	40			30 00	18 00							1903	1,580	
22-40	1903	1907	364													
22-45	1908	1911	1884													
40-80	1908	1914	10										36,000			
15-30	1909		7													Horiz Cyl, (Recalled)
15-30 (Vert Cyl)	1910	1911	100													
20-40 (Vert Cyl)	1911	1914	200													
30-60	1911	1916	1,872													
60-100	1912	1912											52,000			
12-27	1913	1914	224													
18-35	1914	1919	425													
Little Devil (15-22)	1914	1916	725			22 00	15 00	2								1 Centered wheel rear, 2 wheels front

New Hart & Parr Models

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
25 (12-25) &	1918	1922	9,075			25 00	12 00	2								
30 (15-30 A)	1918	1922				30 00	15 00									

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
20 (10-20 B)	1920	1922	320	1921	0079	23 01	14 08	2/281	2/1	2 00	3 00		3,990			
20 (10-20 C)	1922	1924	422			20 00	10 00									
30 (15-30 C)	1922	1924	1,301	1920	0026	31 37	15 56	2/464	2/1	1 98	2 88	Kero	5,450			
40 (22-40)	1923	1927	499	1923	0097	46 40	28 23	4/616				Kero	8,300			
16-30 E	1924	1926	1,500	1924	0106	37 03	24 79	2/464					6,000			
12-24 E	1924	1926	1,100	1924 1926	0107 0129	26 97 31 99	16 99 21 77	2/308 2/337	2/1	2 66	3 33	Kero Dist	4,675 5,440			
16-30 F	1926		2,000	1924	0106	37 03	24 79	2								
12-24 G	1926	1927	800	1924	0107	26 97	16 99	2								
18-36 G	1926	1927	2,851	1926	0128	36 97		2/500	2/1	2 00	3 00	Dist				
18-36 H	1927	1927	4,902													
12-24 H	1927	1930	5,352	1926	0129	31 99	21 77	2					5,440			
28-50	1927	1928	451	1927	0140	64 56	43 58	4/674				Dist	10 394			Narrow radiator
18-36 I	1928	1930	6945	1926	0128	42 85	32 25	2	2/1	2 00	3 00		7,325			
28-50	1928	1930	749	1927	0140	64 56	42 58	2	2/1			Dist	10,394			Wide radiator

(Gay 1997; Sanders 1996; Wendel 1993)

TABLE 40

INTERNATIONAL HARVESTER CORPORATIONMODELS

International Models

Model	Prod From	Prod To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	Speed To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
15-30	1921			1920	0024	36.98	26 00	4	2/1	1 85	2 48	Kero	8,990			
				1922	0087	30 16	15 35	4				Kero	6,000			First w/ ball-bearing crankshaft bearings
8-16			8,000	1920	0025	16 50	11 00	4	3/1	1 81	4 10		3,660			First production PTO
TD-18				1939	0315	80 32	72 38	6	6/1	1 50	5 75		23,360			"TRACTRACTER" crawler
TD-14				1940	0343	61 56	51 43		6/1	1 50	5 75	Gas	17,595			"TRACTRACTER" crawler
T-9				1940	0344	43 93	34 28	4	5/1	1 50	5 30	Diesel				"TRACTRACTER"
				1941	0372	46 03	32 29	4	5/1	1 50	5 25	Gas	10,830			crawler
				1951	0461	41 59	31 32	4/335	5/1	1 50	5 30	Diesel	11,660			
T-6				1940	0345	34 54	26 75	4	5/1	1 50	5 40	Diesel	7,950			"TRACTRACTER"
				1940	0346	36 06	28 52	4	5/1	1 50	5 40	Gas				crawler
				1940	0347	31 21	28 45	4	5/1	1 50	5 40	Dist				
				1951	0462	34 38	25 45	4	5/1	1.50	5.40	Diesel	8,585			
TD-14A				1950	0445	71 79	49 50	4/461	6/1	1 60	5 70	Diesel				"TRACTRACTER" crawler
TD-18A				1950	0446	97 83	67 04	6/681				Diesel	25,995			"TRACTRACTER" crawler

TD-24				1950	0447		138 13	6/1091	8/1	1 60	7 80	Diesel	40,595			"TRACTRACTER"
				1954	0529		154 05	6/1091	8/1	1 60	8 00	Diesel				crawler No brake tests – no capacity
W-400				1955	0533	45 64	35 73	4/264								
				1955	0535	46 61	33 58	4/264				Dist	6,699			
300 Utility				1955	0539	36 44	29 87	4/169	5/1	2 60	16 74		4,413			

(Larsen 1981; Wendel 1993; Pripps and Morland 1998)

McCormick and McCormick-Deering FARMALL Models

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
Regular				1925	0117	20 10	12 70		3/1	2 00	4 00	Kero	4,100	1925	925	
F-30	1931	1939		1931	0198	32 80	24 60		4/1	2.00	3 75	Kero	5,990			
F-12	1932	1938	123,441	1933	0212	16 20	10 10	4	3/1	2 25	3 75	Gas	3,280			
				1933	0220	14 60	11.80	4	3/1	2 25	3 75	Kero	3,240			
F-20			148,969	1934	0221	23 10	15 40	4	4/1	2 25	3 75	Kero	4,545			
				1936	0264	26 80	18 80	4	4/1	2 25	3 75	Dist	4,400			
				1936	0276	26 70	19 60	4	4/1	2 25	3 75	Dist	4,310			
F-14			31,902	1938	0297	17 00	13 20	4				Dist	4,900			
M	1939	1952	288,000	1939	0327	34 20	25 50	4/248	5/1	2 67	16 36	Dist	6,779			
				1939	0328	36 10	24 50	4	5/1	2 67	16 36	Gas	6,770			
A	1939	1954	220,000	1939	0329	16 80	12 30	4	4/1	2 25	10 00	Gas	3,570	1939	600	Total Production – As & Super As
				1939	0330	15 18	15 17	4	4/1	2 25	10 00	Dist				
B				1939	0331	16 82	13 04	4	4/1	2 25	10 00	Gas	3,740	1939	600	
				1939	0332	15 36	11 55	4	4/1	2 25	10 00	Dist				
H	1939	1964		1939	0333	24 28	19 84	4/152	5/1	2 67	16 36	Gas	5,550	1939	750	Add $175 for pneumatic tires
				1939	0334	20 80	19 38	4	5/1	2 67	16 36	Dist	5,550			
MD				1941	0368	31 17	25 40	4	5/1	2 67	16 36	Dist				
				1951	0460	38 21	27 54	4	5/1	2 67	16 25	Dist	5,861			
Cub				1947	0386	9 23	6 75	4/60	4/1	2 14	6 40	Dist	1,477			

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
C				1948	0395	19 91	15 00	4/113	4/1	2 36	10 25	Gas				
Super C				1951	0458	22 92	16 29	4/122	4/1	2 36	10 25	Gas	3,209			
Super M	1952	1954		1952	0475	41 33		4/264	5/1	2 67	16 75	Gas	5,603			
				1952	0476	44 20		4/264	5/1	2 67	16.13	Gas	5,515			
Super MD				1952	0477	46 73	33 03	4	5/1	2 67	16 75	Dist	6,034			
Super H	1952			1953	0492	31.30	23 48	4/164	5/1	2 67	16 25	Gas	4,389			
100				1955	0537	17.95	14 52	4/123	4/1	2 32	10 05	Gas	3,038			
200				1955	0536	22.09	16 85	4/123	4/1	2 50	10 67	Gas	3,541			
300	1954	1956		1955	0538	33 89	26.97	4/169	5/1	2 50	16 11	Gas	5,361			
400				1955	0532	48 70	35.60	4	5/1	2 50	16 70	Gas				
400				1955	0534	46 73	33.58	4/264				Diesel				

(Larsen 1981; Wendel 1993; Pripps and Morland 1998)

TABLE 41
MASSEY-HARRIS-FERGUSON CORPORATION MODELS

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
General Purpose				1930	0177	24 84	15 64	4	3/1	2 20	4 00	Gas				4-Wheel drive
				1931	0191	22 50	16 76	4	3/1	2 20	4 00	Dist				Same equip save for fuel
3-4 Plow				1933	0219	44 24	26 45	4	3/1	2 50	4 00	Dist	5,385			
Challenger				1936	0265	26 21	16 29	4	4/1	2 40	8 5	Dist	4,200			
Pacemaker				1936	0266	27 52	18 45	4				Dist	4,050			
Twin Power Challenger				1937	0293	36 27	23 90	4	4/1	2 40	8 50		4,570s 5,900r			
Twin Power Pacemaker				1937	0294	31 94	20 26	4	4/1	2 40	8 50	Gas				
101 S				1938	0306	31 50	23 94	6					3,850s 5,725r			
101 R				1938	0307	31.40	24 79	6								Same as 306 except tri-cycle
				1941	0377	40 90	28 08		4/1	2 68	17 85		3,865			
101 R Junior				1939	0318	23 78	16 44	4	4/1	2 60	17 40	Gas	4,612			
				1940	0359	30 15	18 30	4	4/1	2 60	17 40					
55				1948	0394	55 72	41 10	4	4/1	2 96	12 07	Gas	7,223			
				1951	0455	63 50	58 05	4/382	4/1	2 96	12 07	Gas	7,520			
81 R				1941	0376	26 08	16 41	4	4/1	2 50	16 00		2,895			
44 RT				1947	0389	44 07	31 24	4	5/1	2 48	13 80		6,925			
Pony				1948	0401	10 38	8 36	4	3/1	2 74	7 00		1,890			
22 RT				1948	0403	26 92	17 95	4	4/1	2 45	13 02		2,928			
30 RT				1949	0409	33 03	20 64	4	5/1	2 58	12 63		3,667			
44 Diesel Standard				1949	0426	41 82	29 64	4	5/1	2 21	12 28		5,085			

44 K Standard	1949	0427	35 66	27 70	4					
55 K Standard	1949	0428	46 44	37 25	4	4/1	2 96	12 07		7,265
55 Diesel	1950	0452	51 35	41 32	4/382	4/1	2 96	12 07	Diesel	7,793
33 RT	1953	0509	36 23	28 02	4	5/1	2 75	13 46		5,191
44 Special	1953	0510	45 23	34 71	4/277	5/1	2 24	12 50		5,789
No 16 Pacer	1954	0531	17 88	13 03	4/91	4/1	3 02	13 03		2,299

Wendel 1993; Williams 1992a)

TABLE 42

MINNEAPOLIS-MOLINE COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ec Cost Year	$	Design Market & Features
ZAU (or 2A)																GP row crop, tricycle front, 2 wheel
ZAN																GP row crop, tricycle front, 1 wheel
ZAE																Adj wide front and rear
ZAS																Standard tread
GTC												LPG				
KT	1930	1938				23 00	14 00									Kombination Tractor
Universal MTA	1935															Updated MT
Universal J	1935								5/1		12 20					
Z	1937															"Visionlined", row crop
U	1938															
ZA	1948															
Moline D, 9-18				1920	0033	27 45	17 40	4/		3 58			3,590			
UDLX	1938	1941	150	1938		38 12	30 86	4			40 00					"Comfortractor", Deluxe U, enclosed cab
GT	1939			1939	0317	31 60	36 96	4		2 7	9 6	Gas	9,445			Standard
R	1939	1941	400	1940		20 49	15 58									Tricycle or standard
U Standard				1949	411	41 51	32 56	4	5/1	2 70	14 80	Pro				
G				1950	437	55 94	39 20	4/403	5/1	2 50	13 80	Gas	7,230			

Z	1950	438	34 77	25 18	4/206	5/1	2 40	13 10	Gas	4,290
R	1951	468	25 92	18 29	4/165	4/1	2 60	13 20	Gas	3,414
BF	1951	469	23 53	19 12	4/133	4/1	2 42	13 12	Gas	2,894
UB	1954	520	46 26	42 91	4/238	5/1	2 80	15 60	Gas	6,037
U Trac	1954	521	36 05	26 83	4/283	5/1	2 50	14 00	Fuel	5,905
UB	1954	522	45 24	35 74	4/283				LPG	

(Wendel and Morland 1990, 1993; Sayers 1996)

TABLE 43
MINNEAPOLIS THRESHING MACHINE COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
12-25	1920	1926		1920	0013	26 24	16 26	4	2/1	2 21	2 98					
22-44				1920	0014	46 00	33 00	4				Kero	12,410			
35-70				1920	0015	74 01	52 55	4	1/1	2 10	2 10		22,500			
17-30				1921	0070	31 95	19 69		2/1	2 06	2 70	Kero	6,000			
17-30 Type B				1925	0118	34 76	22 37	4		2 33	3 05		7,550			Lugs standard
27-42				1929	0162	42 30	33 99	4	2/1	2 69	3 42	Kero	8,373			
39-57				1929	0163	64 55	47 77	4				Gas	9,695			

(Wendel and Morland 1990, 1993; Sayers 1996)

TABLE 44
MONARCH CRAWLER MODELS – BEFORE AND AFTER PURCHASE BY ALLIS-CHALMERS

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
Monarch D, 6-60				1924	0108	70 74	51 51	6	3			Gas	16,789			
Monarch C, 25-35				1925	0113	43 67	37 59	4	3			Gas	10,630			
Monarch 75, Model F, 10 Ton				1927	0139		59 56		3			Gas	21,700			
Monarch 50, 6-Ton				1927	0147		50 55	4	3			Gas				
Monarch 35, 35-30				1929	0171		40 99	4	3			Gas	10,680			
Monarch 50				1930	0179	62.18	53 28	4	3	1 82	3 99		15,100			
L	1931	1942	3,389	1932	0200	80 46	75 66	6	6	1 94	6 47	Gas	22,027			
				1939	0338	1 8 84	93 65		6	1 48	6 41	Gas	26,105			
LO				1937	0287	91 56	76 42	6	6/2	1 48	6 41	Diesel	24,925			
M	1932	1942	14,524	1933	0216		29 65	4	4	2 23	5 82		6,620			
				1935	0239	31 64	22 79		4	1 83	4 15		6,855			
K/KO	1929	1939	8,261	1939	0336	54 54	41 5	4	3	1 72	5 92					
				1937	0285	53 41	50 45	4	4	1 72	5 92		13,000			
S/SO	1937	1942	1,224	1939	0337	84 34	72 92	4/675	5	1 52	6 37	Gas	20,330			
				1937	0286	66 64	62 97	4/675	5	1 51	6 37	Diesel	20,100			
HD14/14C	1939	1947	6,404	1940	0362	128 17	99 39	6	6	1 72	7 00		28,750			
HD7/7W	1940	1950	18,503													
				1940	0360	60 52	57 31	3	4	1 84	5 82		14,175			
HD10/10W	1940	1950	10,197													
				1940	0361	86 45	65 55	4	6	1 69	6 03		21,630			

HD3	1942		28										
HD5B	1946	1955	29,255	1948	0396		38 00		5	1 42	5 47	Diesel	11,815
HD19H	1947	1950	2,650	1948	0397	129 08	101 53	6		0 00	7 00		40,395
HD9	1950	1955	5,850	1951	0463	71 93	67 00	4	6	1 39	5 68		19,945
HD15	1950	1955	3,909	1951	0464	105 73	105 04		6	1 39	5 80		30,985
HD20	1951	1954	3,100	1951	0465		114 87	6/660				Diesel	42,625
HD21AC				1955	0550		132 26	6/844					44,725
HD16AC				1955	0551		104 96	6/844					32,135
HD16A				1955	0552		93 56	6/844	6	1 4	5 8		32,375

(Swinford 1996; Wendel 1993)

TABLE 45
OLIVER FARM EQUIPMENT COMPANY MODELS

Oliver Models

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
99	1938	1952										Gas				
99	1953	1957														90 & 99 merged
90				1930	0183	49 04	28 44	4	3/1	2 23	4 33	Kero	6,415			Originally known as Oliver Hart-Parr 3-5 Plow , then Oliver 28-44 and finally Oliver 90
RC 80 KD	1937	1948		1938	0300	36 33	27 13	4/334	3/1	2 70	4 33	Dist	4,930			Tested with steel wheels in RC configuration
80 Standard KD	1937	1948		1938	0301	37 03	27 97	4/339				Dist	4,950			Tested with steel wheels in standard configuration Rubber tires also available
RC 80 KD	1937	1948		1938	0300	35 14	23 27					Fuel				Kerosene or diesel
80 Standard HC				1940	0365	38 11	32 67	4	4/1	2 78	6 44	Gas	6,770			
RC 70 HC	1935	1948		1940	0351	30 37	22 72	6	6/1	2 56	13 44	Gas	6,770			
RC 70 HC	1935	1948		1940	0351	28 37	22 64	6/201	4/1			Gas				Standard, orchard & industrial
90	1938	1952		1940	0183	36 07	27 66					Kero				Model 90 & 99 same but for fuel
RC 60 HC				1941	0375	18 35	15 17	4	4/1	2 58	6 10		2,450			
RC 60	1940	1948		1941	0375	18 35	15 17	4/120	4/1	2 58	6 10		2,450			
RC 88 HC				1947	0388	41 99	37 00	6/231				Gas				
Standard 88 HC				1948	0391	43 15	29 08	6/231	6/1	2 51	11 80	Gas	4,863			
RC 77 HC				1948	0404	33 98	28 70	6/194	6/1	2 67	12 25	Gas	3,831			
Standard 77 HC				1948	0405	33 56	22 64	6/194				Gas	4,036			
RC 66 HC				1949	0412		24 91	4/129				Gas				
Standard 66 HC				1949	0413	24 90	16 96	4/129	6/1			Gas	2,919			
RC 77 HC				1949	0425	37 17	25 75	6/194	6/1			Gas				
HG				1949	0434		25 30	4/133	3/1			Gas	4,183			Crawler

	Prod			Neb		HP				Speed				Ex Cost		
Model	From	To	Units	Year	#	Bhp	DB hp	Cyl/ Disp	Trans	From	To	Fuel	Wt	Year	$	Design Market & Features
DG				1949	0435	60 88	45 62	6	4/1				14,645			Crawler
DD				1949	0436		73 30		4/1	1 45	4 85		15,515			
RC 88 Diesel				1950	0450	43 53	38 30	6/231				Diesel				
99				1950	0451	62 28	46 40	4/443				Gas				
RC 77 Diesel				1951	0457	35 79	27 80	6/194				Diesel				
77 Row Crop				1951	0457	31 61	25 14	6/194	6/1			Diesel	4,932			
RC 66 Diesel	1949	1952		1951	0467	25 03	17.70	4/129	6/1	2 50	11 36	Diesel	3,795			
77				1952	0470	32 51	25 79		6/1			LPG				
OC-18				1952	0489		101 62	6/				Diesel	35,090			Crawler – No capacity on dynamometer, no Bhp test
OC-6				1954	0516		31 92	6/194	6/1	1 88	8 86	Gas	6,600			Crawler
				1954	0517		33 19	6/194				Diesel	6,742			Crawler
Super 55 HC				1954	0524	32 65	23 37	4/144	6/1				3,359			
Super 88 HC				1954	0525	53 14	36 84	6/265	6/1	2 49	11 75	Gas	5,513			
Super 55 Diesel				1954	0526	33 71	28 97	4/144				Diesel	3,467			
Super 88 Diesel				1954	0527	54 88		6/265				Diesel				

Oliver Hart-Parr Models

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
28-44 (Hi Comp Sp)	1930	1937														
28-44	1930	1937		1930	0183	49 04	28 40	4/443				Kero				
RC 18-27	1930	1937		1930	0176	29 72		4/280				Kero				2 Wheel front
18-28	1930	1937		1930	0180	30 29		4/280				Kero				Standard, western, rice field & orchard
RC 70 KD				1936	0267	27 15		6/201				Fuel				Kero or diesel
				1936	0284	26 75		6/201				Fuel				
RC 70 HC	1935			1936	0252	26 6	18 00	6/201				Gas	3,500			Row crop
Std 70 HC				1937	0283											

(Gay 1997; Sanders 1996; Wendel 1993; Morrill and Hackett 1996)

TABLE 46
TWIN CITIES COMPANY

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
60/110	1913	1924						6								
60/90	1913	1924											28,000			
TC-15	1915														1,200	
TC-25	1915														2,450	
TC-40	1915														3,250	
TC-60	1915														4,200	
40-65				1920	0048	65 96	49 71	4		1 90	1 9	Kero	25,500			
12-20	1919			1920	0019	27 93	18 49	4	2/1	2 20	2 9	Kero				4 valves per cylinder
20-35	1919			1920	0067	46 88	34 12		2/1	2 20	2 9	Kero	8,100			
TY, 17-28	1924			1926	0121	30 91	22 50	4				Kero	5,895			
AT, 27-44	1929	1935		1926	0122	49 05	27 00		2/1			Kero				
FT, 21-32	1929			1926	0127	35 88	31 05	4	2/1	2 20	2 9	Kero	6,189			
FT, 21-32				1928	0152	39 14	29 16	4	3/1	2 36	4 45		6,463			
KT, 11-20				1930	0175	25 83	18 80		3/1	2 10	4 14	Kero	5,060			

(Wendel 1993)

TABLE 47
WATERLOO BOY GASOLINE TRACTION ENGINE COMPANY MODELS

Model	Prod From	To	Units	Neb Year	#	HP Bhp	DB hp	Cyl/ Disp	Trans	Speed From	To	Fuel	Wt	Ex Cost Year	$	Design Market & Features
Froelich Prototype	1892		1													First gasoline tractor to propel itself forward and backward
Froelich	1893		1			25 00		1								
Waterloo Gasoline Engine Co	1896		1			25 00										
Waterloo Gasoline Engine Co	1897		1			25 00										
W B Std Mod "TP"	1912	1913						4								Cross-mounted engine
W B Sure Grip, Never Slip	1913															Rear crawler tracks with cross-mounted engine
W B Light or L	1913	1914	36			15 00	7 00	2/333	1				3,000			
W B C	1913					15 00										
W B R – Style A	1914		17			20 00		2/333				Kero				
W B R – Style B	1914	1915	29			24 00		2/395				Kero				
W. B R – Style C	1915		9,310*			24 00	12	2/465	1			Kero	6,200	1917	850	465 cu In * - All R's
N	1917	1924	21,392	1920	0001	25 00	12 00	2/465	2/1	2 25	3 00	Kero	6,183	1921	1,050	

Deere (2) 1996; Brunswick 2001; Johnny Popper 2001; Wendel 1993)

REFERENCE LIST

AGCO Corporation. 2001. Available from: http://www.agcocorp.com/ home.asp; Internet; accessed 28 February 2001.

Agnew, John A. 1979. Instrumentalism, realism, and research on the diffusion of innovation. *Professional Geographer* 31, no. 4: 364-70.

Alston, Lee J. 1981. Tenure choice in southern agriculture, 1930-1960. *Explorations in Economic History* 18, no. 3: 211-32.

________. 1983. Farm foreclosures in the United States during the inter-war period. *Journal of Economic History* 43, no. 4: 885-903.

Ankli, Robert E. 1977. Farm income on the Great Plains and Canadian prairies, 1920-1940. *Agricultural History* 51, no. 1: 92-103.

________. 1980. Horses vs. tractors on the Corn Belt. *Agricultural History* 54, no. 1: 134-48.

Arnold, Roger A. 1998. *Microeconomics*. Cincinnati, OH: South-Western College Publishing.

Baker, Oliver E. 1928. Agricultural regions of North America: Part VI, the spring wheat region. *Economic Geography* 4: 399-433.

Beal, George M., Everett M. Rogers, and Joe M. Bohlen. 1957. Validity of the concept of stages in the adoption process. *Rural Sociology* 22, no. 2: 166-8.

Brunswick. 2001. Available from: http://www.brunswickmicro.nb.ca/coates/hp.htm; Internet; accessed 26 February 2001.

Carroll, John. 1998. *The world's greatest tractors.* Broomall, PA: Chelsea House Publishers.

Case Corporation. 2001. Available from: http://www.casecorp.com/corporate/ history/index.html; Internet; accessed 28 February 2001.

Cavert, William. 1956. The technological revolution in agriculture, 1910-1955. *Agricultural History* 30, no. 1: 18-27.

Chapin, F. Stuart. 1928. *Cultural change*. New York: Century Co.

Churchill, Ruel V. 1944. *Modern operational mathematics in engineering*. New York: McGraw Hill Book Company, Inc.

Clarke, Sally. 1991. New Deal regulation and the revolution in American farm productivity: A case study of the diffusion of the tractor in the Corn Belt, 1920-1940. *Journal of Economic History* 51, no. 1: 101-23.

Cochran, Thomas C. 1983. *Frontiers of change: Early industrialism in America*. New York: Oxford University Press.

Cockshutt. 1999. Available from: http://cockshutt.com/history.html; Internet: accessed June 30, 1999.

Cockshutt Models. 1999. Available from: http://www.sckans.edu/~alan/tractsn.html; Internet; accessed 13 July, 1999.

Cockshutt Shed. 1999. Available from: http/:www.ciaccess.com/~jackson1/shed/homepage.html; Internet; accessed July 21, 1999.

David Brown. 1999. Available from: http://www.davidbrown.com/corpinfo/history2.htm; Internet; accessed 17 August, 1999.

Day, Richard H. 1967. The economics of technological change and the demise of the sharecropper. *American Economic Review* 42, no. 3: 427-49.

Deere History. 1999. Available from: http://www.greenlinesales.com/JDstory.htm; Internet, accessed 23 Aug 1999.

Deere, John & Co. 1988. *How Johnny Popper replaced the horse*. Moline, IL: John Deere & Co.

Deere, John & Co. 1994. *John Deere tractors, 1918-1994*. Moline, IL: John Deere & Co.

Deutz. 2001. Available from: http://www.deutz.de/index4.htm; Internet; accessed 14 May 2001.

Deutz History. 2001. Available from: http://deutz.de/info/chronik/ecdeutz.htm; Internet; accessed 15 May 2001.

Dinsmore, Wayne. 1922. The efficient use of animal power. *Agricultural Engineering* 3, no. 1: 23-7.

Duram, Leslie A., and Kelli L. Larson. 2001. Agricultural research and alternative farmers information needs. *Professional Geographer* 53, no. 1: 84-96.

Dust Bowl. 2001. Available from: http://www.pbs.org/wgbh/amex/dustbowl/ timeline/index.html; Internet; accessed 1 March 2001.

Economic History. 2001. Available from: http://eh.net/hmit/; Internet; accessed on 3 March 2001.

Ellenberg, George B. 1998. African Americans, mules, and the southern mindscape, 1850-1950. *Agricultural History* 72, no. 2: 381-98.

________. 2000. Draft animals, tractors, and the United States Department of Agriculture. *Agricultural History* 74, no. 6: 545-68.

Epping, Rod, and Chris Epping. 2001. Available from: http://members.tripod.com/ Rumelypull /Rumely.html; Internet; accessed 16 April 2001.

Erb, David, and Eldon Brumbaugh. 1993. *Full steam ahead – J. I. Case tractors & equipment, 1842-1955*. St. Joseph, MI: American Association of Agricultural Engineers.

Fay, Guy, and Andy Kraushaar. 1998. *Farmall letter series tractors.* Oceola, WI: MBI Publishing Company.

Federal Reserve Bank of Kansas City. 1996. *Economic forces shaping the Rural Heartland.* Kansas City, MO: Federal Reserve Bank of Kansas City.

Ford History. 1999. Available from: http://www.hfmgv.org/histories/fmc/ fmc.chrono.html; Internet; accessed 28 August 1999.

Ford Motor Company. 1919. *The Fordson at work.* Highland Park, MI: Ford Motor Company.

Ford, Henry. 1923. *My life and work.* Garden City, NY: Doubleday, Page & Company.

Garrett, Martin, Jr. 1990. The mule in southern agriculture: A requiem. *Journal of Economic History* 50, no. 4: 925-30.

Gates, Paul W. 1977. Homesteading in the high plains. *Agricultural History* 51, no. 1: 109-33.

Gay, Larry. 1997. *A guide to Hart-Parr, Oliver, and White Farm tractors, 1901–1996.* St. Joseph, MI: American Society of Agricultural Engineers.

Gould, Peter R. 1969. *Spatial diffusion.* Washington, DC: Association of American Geographers.

Gray, R. B. 1975. *The agricultural tractor, 1855-1950.* Saint Joseph, MI: American Society of Agricultural Engineers.

Grubler, Arnuf. 1996. Time for change on the patterns of diffusion of innovation. *DAEDALUS – Journal of the American Academy of Arts and Sciences* 125, no. 3: 19-42.

Gunlogson, G. B. 1957. Needed: A substitute for a team of mules. *Agricultural Engineering* 38: 162-3.

Hackett, Jeff, and Brian Rukes. 2001. *American farm tractors.* Osceola, WI. MBI Publishing Company.

Hägerstrand, Torsten. 1967. *Innovation diffusion as a spatial process.* Trans. Allen Pred. Chicago, IL: University of Chicago Press.

Halberstadt, April. 2000. *Farm tractors.* New York: MetroBooks.

Halsey, Francis Whiting. 1920. *The literary digest history of the World War.* New York: Funk & Wagnalls Company.

Harry Ferguson. 1999. Available at: http//www.geocities.com/motorcity/downs/9828/; Internet; accessed 27 July 1999.

Hassinger, Edward. 1959. Stages in the adoption process. *Rural Sociology* 24, no. 1: 52-3.

Himdle, Brooke, and Stephen Lubar. 1988. *Engines of change: The American Industrial Revolution, 1790 – 1860.* Washington DC: Smithsonian Institution Press.

Historical Census Data. 2001. Available from: http://fisher.lib.virginia.edu/ census/; Internet; accessed 3 March 2001.

Hohn, Franz E. 1958. *Elementary matrix algebra.* New York: The Macmillan company.

Johnson, H. Thomas. Winter 1973-74. Postwar optimism and the rural financial crisis of the 1920s. *Explorations in Economic History* 11, no. 2: 173-92.

Johnny Popper. 2001. Available from: http://johnnypopper.com/home.shtml; Internet; accessed 26 February 2001.

Jones, Gwyn E. 1960. The differential characteristics of early and late adopters of farming innovations. *University of Nottingham, School of Agriculture Report:* 75-80.

________. 1963. The diffusion of agricultural innovations. *Journal of Agricultural Economics* 15, no. 3: 387-404.

________. 1967. The adoption and diffusion of agricultural practices. *World Agricultural Economics and Rural Sociology Abstracts* 9, no. 3: 1-34.

Jordan-Bychkov, Terry G., and Mona Domosh. 1999. *The human mosaic.* New York: Addison-Wesley Educational Publishers.

Kauffman, Kyle D. 1993. Why was the mule used in Southern agriculture? Empirical evidence of principal-agent solutions. *Explorations in Economic History* 30, no. 3: 336-51.

King, Alan C. 1989a. *Allis-Chalmers, 1918-1960: An informal history.* Delaware, OH: Independent Print Shop Company.

________. 1989b. *The Fordson and Ford tractors, 1918-1960.* Delaware, OH: Independent Print Shop Company.

King, Willford I. 1929. The gasoline engine and the farmer's income. *Journal of Farm Economics* January: 64-78.

Klancher, Lee. 1995. *Farmall tractors.* Osceola, WI: Motorbooks International Publishers & Wholesalers.

Klemm, Friedrich. 1964. *A history of Western technology.* Cambridge, MA: M.I.T. Press.

Landels, J. G. 1978. *Engineering in the ancient world.* Berkeley, CA: University of California Press.

Larsen, Lester. 1981. *Farm tractors, 1950-1975.* St. Joseph, MI: American Society of Agricultural Engineers.

Leffingwell, Randy. 1994. *Caterpillar.* Osceola, WI. Mototbooks International Publishers & Wholesalers.

________. 1998. *Ford farm tractors.* Osceola WI: Motorbooks International Publishers & Wholesalers.

Letourneau, Peter. 1993. *John Deere: General purpose tractors, 1928-1953.* Osceola WI: Motorbooks International Publishers & Wholesalers.

________. 1997. *Vintage Case tractors.* Stillwater, MN: Voyageur Press.

Lew, Byron. 2000. The diffusion of tractors on the Canadian prairies: The threshold model and the problem of uncertainty. *Explorations in Economic History* 37, no. 2: 189-216.

MacLeod, Christine. 1992. Strategies for innovation: The diffusion of new technology in nineteenth-century British industry. *Economic History Review* 45, no. 2: 285-307.

McMillan, Don, and Russell Jones. 1988. *John Deere tractors and equipment: Volume 1, 1837-1959.* St. Joseph, MI: American Society of Agricultural Engineers.

Maddison, Angus. 2000. *The next millennium.* The Wall Street Journal. New York: January 1, 2000: R28.

Malthus, Thomas R. 1798. Available from: http://socserv2.socsci.mcmaster. ca/~econ/ ugcm/ 3ll3/malthus; Internet; accessed 28 February 2001.

Marsh, C. Paul, and A. Lee Coleman. 1954. Farmers' practice-adoption rates in relation to adoption rates of "leaders." *Rural Sociology* 19, no. 2:180-1.

Marti, Donald B. 1980. Agricultural journalism and the diffusion of knowledge: The first half-century in America. *Agricultural History* 51, no. 1: 28-37.

Massey-Ferguson. 1999. Available from: http://www.ssbtractor.com/features/ Massey_Ferguson_tractors.html; Internet; accessed 19 July 1999

Minneapolis Moline. 2002. Available from: http://www.jetstar.minneapolis-moline.com/history.html; Internet; accessed 10 October 2002.

Model T. 2001. Available from: http://modelt.org/; Internet; accessed 19 June 2001.

Morrill, Richard L. 1968. Waves of spatial diffusion. *Journal of Regional Science* 8, no. 1: 1-18.

Morrill, T. Herbert, and Jeff Hackett. 1996. *Oliver farm tractors.* Osceola, WI. Motorbooks International Publishers & Wholesalers.

Mott, Lawrence V. 1997. *The development of the rudder: A technological tale.* London, England: Chatham Publishing.

Murphy, James C. 1998. *On the geography of technological development*. Huntsville, TX: Unpublished paper, Sam Houston State University.

Musoke, Moses S. 1981. Mechanizing cotton production in the American South: The tractor, 1915-1960. *Explorations in Economic History* 18, no. 4: 347-75.

Newman, James R. 1956. *The world of mathematics.* New York: Simon and Schuster.

O'Conner, John J. and Edmund F. Robertson. 1999. Accessed from: http://www-groups.dcs.st-and.ac.uk/~history/; Internet; accessed 28 February 1999.

Olmstead, Alan L., and Paul W. Rhode. 1988a. An overview of California agricultural mechanization, 1870-1930. *Agricultural History* 62, no. 3: 86-112.

________. 1988b. The farm energy crisis of 1920. *Agricultural History* 62, no. 1: 48-60.

________. 1994. The agricultural mechanization controversy of the inter-war years. *Agricultural History* 68, no. 3: 35-53.

Orlemann, Eric. 1998. *Caterpillar*. Osceola, WI: MBI Publishing Company.

Oster, Sharon M. 1999. *Modern competitive analysis*. New York: Oxford University Press.

Pemberton, H. Earl. 1936. The curve of culture diffusion rate. *American Sociological Review* 1, no. 4: 547-56.

________. 1937. The effect of a social crisis on the curve of diffusion. *American Sociological Review* 2, no. 1: 55-61.

Pratt, Marianna. 1985. Deutz-Allis and the switch from A-C. *Agricultural Engineering* 66, no. 7: 8-10.

Pripps, Robert N. 1994. *Oliver tractors: History of Oliver, Hart-Parr, Cockshutt and Cletrac tractors, model development, variations, and specifications*. Osceola, WI: Motorbooks International Publishers & Wholesalers.

Pripps, Robert N., and Andrew Morland. 1992. *Ford tractors: N series, Fordson, Ford and Ferguson, 1914-1954.* Osceola WI: Motorbooks International Publishers & Wholesalers.

________. 1993. *Farmall tractors: History of International McCormick-Deering Farmall tractors*. Osceola, WI: Motorbooks International Publishers & Wholesalers.

________. 1994. *Oliver tractors.* Osceola, WI: Motorbooks International Publishers & Wholesalers.

________. 1997. *Vintage Ford tractors.* Stillwater, MI: Voyageur Press.

________. 1998. *Great American Tractors – John Deere, Farmall & Ford.* Osceola, WI: MBI Publishing Company.

Prunty, Merle, Jr. 1955. The Renaissance of the Southern plantation. *Geographical Review* 45, no. 4: 459-91.

Rasmussen, Henry. 1993. *International McCormick tractors.* Osceola, WI. Motorbooks International Publishers & Wholesalers.

Rasmussen, Wayne D. 1962. The impact of technological change on American agriculture. *Journal of Economic History* 22, no. 4: 578-98.

Riney-Kehrberg, Pamela. 1989. In God we trusted, in Kansas we busted ... Again. *Agricultural History* 63, no. 2: 187-201.

Robertson, Maxine, Jacky Swan, and Sue Newell. 1996. The role of networks in the diffusion of technological innovation. *Journal of Management Studies* 33, May: 333-59.

Rogers, Everett M. 1958. Categorizing the adopters of agricultural practices. *Rural Sociology* 23, no.4: 345-54.

________. 1995. *Diffusion of innovations.* New York: Free Press Division of Simon & Schuster.

Rumely. 1999. Advance-Rumely Oil Pull Tractors. Available from: www.allischalmers.com/rumely/; Internet; accessed 23 November 1999.

Rural Electrification. 2001. Available from: http://www.rra.dst.tx.us/c&t/ history/grayson/%5C%5CHistory1%5CRURAL%20ELECTRIFICATION.htm; Internet; accessed 1 March 2001.

Russell, Bertrand. 1953. *The impact of science on society.* New York: Simon and Schuster.

Ryan, Bryce. 1948. A study in technological diffusion. *Rural Sociology* 13, no. 3: 273-85.

Ryan, Bryce, and Neal C. Gross. 1943. The diffusion of hybrid corn in two Iowa communities. *Rural Sociology* 8, no. 1: 15-24.

Salisbury, J. Kenneth (editor). 1950. *Kent's mechanical engineer's handbook: Power volume.* New York: John Wiley and Sons.

Saloutos, Theodore. 1969. The New Deal and farm policy in the Great Plains. *Agricultural History* 43, no. 3: 345-55.

Sanders, Ralph W. 1996. *Vintage farm tractors: The ultimate tribute to classic tractors.* Stillwater, MN: Voyageur Press.

Sayers, Al. 1996. *Minneapolis-Moline tractors.* Osceola, WI: Mototbooks International Publishers & Wholesalers.

Schlebecker, John T. 1977a. Farmers and bureaucrats: Reflections on technological innovation in agriculture. *Agricultural History* 51, no. 4: 641-55.

________. 1977b. Farmers and bureaucrats: Reflections on technological innovation in agriculture. *Agricultural History* 51, no. 4: 641-55.

Snow, Thad. 1954. Proud Kate: The aristocratic mule. *Harper's Magazine* 209: 64-8.

Sobel, Dava. 1996. *Longitude: The true story of a lone genius who solved the greatest scientific problem of his time.* New York: Penguin Books USA.

Sorensen, Charles E. 1956. *My forty years with Ford.* New York: W. W. Norton & Company.

Starr, Chauncey, and Richard Rudman. 1973. Parameters of technological growth. *Science* 182, no. 4110: 358-64.

Steam Engines and Tractors. 1999. Available from http: //lcweb2.loc.gov/ammem/ award97/ndfahtml/paz_steam.html; Internet; accessed 8 November 1999.

Stearns, Peter N. 1993. The Industrial Revolution in world history. Cambridge, MA: M.I.T. Press.

Steinbeck, John. 1939. *The grapes of wrath.* New York: Viking Press.

Swinford, Norm. 1996. *A guide to Allis-Chalmers farm tractors.* St. Joseph, MI: American Society of Agricultural Engineers.

Toynbee, Arnold. 1884. *Lectures on the Industrial Revolution in England.* Available from: http://www.socsci.mcmaster.ca/~econ/ugcn/3113/ toynbee/indrev; Internet; accessed 17 March 2001.

USDA. 2001. Available from: http://www.usda.gov/history2/text4.htm; Internet; accessed 27 February 2001.

Wendel, C. H. 1993. *Nebraska tractor tests since 1920.* Osceola, WI: Motorbooks International Publishers & Wholesalers.

Wendel, C. H., and Andrew Morland. 1990. *Minneapolis-Moline tractors, 1870-1969.* Osceola, WI: Motorbooks International Publishers & Wholesalers.

________. 1992. *Allis-Chalmers tractors.* Osceola, WI: Motorbooks International Publishers & Wholesalers.

________. 1994. *Massey tractors.* Osceola, WI: Motorbooks International Publishers & Wholesalers.

Wik, Reymond M. 1980. The American farm tractor as father of the military tank. *Agricultural History* 54, no. 1: 126-33.

Williams, Michael. 1992a. *Massey-Ferguson tractors.* Ipswich, UK: Farming Press.

________. 1992b. *Ford and Fordson tractors.* Ipswich, UK: Farming Press.

World Population. 1999. Available from: http:///www.beachwood.k12.oh.us/display/ courseshs/historyproblems/plague/ plaguepopchart.html; Internet; accessed June 28, 1999.

VITAE

Mr. Murphy is a native Texan, having been born in Corpus Christi, attended school in Fort Worth, and matriculated to The University of Texas at Austin where he received a bachelor's degree in mechanical engineering (1958) and a master's degree in engineering mechanics (1961).

Mr. Murphy is currently retired following a 35-year career in engineering. Upon graduation from UT, Mr. Murphy entered industry as a mathematician with Shell Development's Exploration and Production Research Laboratory in Houston (1961-1964). He then joined Bonner & Moore Associates (1964-1988), rising from Engineer to Vice-President, Bonner & Moore International. In 1988 Mr. Murphy moved to Setpoint, Inc. as Staff Consultant specializing in refinery yield accounting (1988-1994). Before retiring due to health problems in 1995, he was associated briefly with KBC Advanced Technologies as a Senior Staff Consultant.

In his retirement, Mr. Murphy has embarked on a program of intellectual enrichment. Geography courses were taken first at Houston Community College, then at Sam Houston State University in Huntsville, Texas. This preparation led to his current pursuit of a Master of Science degree with a specialization in geography at Southwest Texas State University in San Marcos, Texas.

Mr. Murphy resides in Houston, Texas with his wife of forty years, Deanna and cat, Arthur. Also in Houston are his daughter Karen and husband Eugene Brennan, his son, Craig Murphy and wife Patricia, and his three grandchildren, Murphy J. Brennan, Christina R. Q. Murphy, and Thomas C. Q. Murphy.

Permanent Address: 2223 Inwood Dr.

Houston, TX 77019-3524

713.523.5639

jcmurphy@academicplanet.com

This thesis was typed by James C. Murphy.