UTILIZING EXPERT SYSTEMS
FOR
TILLAGE SPEED SELECTION

by

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PREFACE

During the data acquisition and model development for the optimization of drive line efficiency, it was discovered that an expert system to derive the major input to the optimization, speed, would be useful. The development of this expert system to select the most desirable speed of tillage has proven to be a challenging experience. Although difficult, this work has allowed me to further develop my skills as both a programmer and a problem solver. Considerable personal satisfaction has been achieved by transforming the concepts of speed selection into the reality of an expert system. I wish to thank all the individuals who have help me to make this project a success. In addition, a number of groups and individuals deserve special credits.

For their time and support, thanks go to the members of my graduate committee, Dr. Stanley Clark, and Dr. Garth Thompson. A special thanks goes to Dr. Mark Schrock, my major advisor, for allowing me a great deal of freedom in this work. His confidence and support are greatly appreciated.

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CHAPTER ONE

INTRODUCTION

Developments in gear up and throttle down research have given light to the fact that it would be possible to automate the tasks of throttle setting and gear selection, given a desired speed of travel and the load encountered. Present research at Kansas State University indicates that this is possible with the closed loop control of existing gear selection aid concepts. These developments, as well as the development of Expert System environments for personal computers, have led to the conclusion that the major input, desired speed, could also be at least partially automated by the use of an Expert System. The resulting speed selection aid could be used to help the tractor operator in the proper selection of tillage speed for given conditions and operations.

The reason for applying expert systems to the speed of tillage problem is that recent research in the area of drive line optimization has revealed that it could be possible, with a continuously variable transmission or other techniques, to automatically control the drive line of tractor to optimize fuel economy and performance. As a result, it has been suggested that the next step in tractor automation would be to find the most desirable operating speed continuously. This would provide the major input to the optimization control system.

During 1981 a project was begun at Kansas State University to develop a means of recommending throttle settings and proper gear selection to the tractor operator. The resulting device was termed a "gear selection aid" [7]. This device displayed the fuel consumption and the fuel savings possible by shifting to a displayed gear and throttle setting. The gear selection aid could remove some of the uncertainty surrounding the gear up-throttle down concept. It demonstrated that the concept did in fact result in a savings of resources. It also resulted in the conclusion that the concept would work better if there were smaller "gaps" between the gears of the transmission. As a result, research is being conducted with the use of a mechanical continuously variable transmission (CVT) coupled with a six speed power shift transmission for agricultural applications. This research is being conducted jointly by the Agricultural Engineering and Mechanical Engineering departments at Kansas State University and involves the development of an automatic control system to optimize an agricultural type drive line. This previous work has assumed that ground speed was nearly constant. Obviously, this need not be true for the optimization of the drive line and has led to the conclusion that the next step in the automation of the tractor would be to automatically select the desired speed for operation. This is due to the fact that the control system optimization inputs are primarily the load and speed of the vehicle. One relatively expedient method to automate speed selection is the use of Expert Systems to aid the operator.

The objective of this project is to develop an Expert System to aid a tractor operator in the selection of the proper speed of tillage for given conditions and operations. This Expert System should be developed is that it could eventually be used with a drive line optimization control system to give the operator best performance at an optimum speed of tillage.

The selection system will be based on ASAE standards [11] that can be substituted for tractor performance information used in the control system. If the system were implemented in the drive line optimization, speed and load transducers, followed by on-board calculations, would provide the information necessary to obtain the system parameters. This makes the objective of the system clear; to select the proper speed of tillage for the given operation and conditions, hopefully in "real time". This objective is to be achieved through the use of an Expert System shell on a IBM compatible personal computer. It will also include some machinery management concepts to include timeliness and personal labor considerations in the determination of the proper speed of tillage.

Due to the limited information available in the ASAE standards, only six tillage operations were included in the expert system. These operations are; plowing, disking, planting, drilling, cultivating, and rotary hoeing. The six operations were chosen on the basis of their relationships of speed to draft, timeliness coefficients and the frequency of performance by typical farmers. Also, load data has been collected for some of these operations during the previous project, so it was desired that they be included in the simulation of the optimization control system. This may be helpful if the Expert System is actually combined with the control system to implement the gear up and throttle down concept.

CHAPTER TWO

REVIEW OF LITERATURE

Recently there has been increasing interest in using expert systems in engineering applications. The use of expert systems for engineering applications is desirable because they are able to use "rules of thumb" to make decisions with even inexact or incomplete information in a specific task domain. This has proven to be particularly useful in Agricultural Engineering. Agricultural Engineering often deals with areas for which only rules of thumb exist for processing available information. This is due to the fact that Agricultural Engineering is often concerned with quantities for which no practical method of measurement exists or areas that deal with the quality of the biological interface. These areas might include job quality, machine performance, and resource or machinery management. In this project expert system techniques were applied to finding a best speed to perform a given tillage task for specific conditions.

No evidence of recent attempts to apply expert systems to determine the speed of tillage could be found. However, some researchers have worked in the area of appling expert systems to other Agricultural Engineering problems. Also, others have worked in the area of drive line performance, monitoring, and optimization. This survey of literature is divided into two areas, expert systems and drive line investigations.

Expert Systems:

Harmon and King [1] provide a very good introduction to expert systems by giving the reader a sense of the key concepts in a very understandable way. Also, an attempt is made to teach the reader enough about expert systems to be able to ask the right questions of a more knowledgeable person. They also give detailed information about several small and large expert system development tools as well as some examples of successful expert systems. They go step by step through the process of developing a small expert system and describe the development of larger systems. In addition, a fairly comprehensive glossary of terms is provided which helps the beginner to become more familiar with the terms used in expert system work.

Winston [2] outlines and presents an overview of artificial intelligence in general and dedicates chapter six to problem solving paradigms, of which expert systems are one implementation. He refers to these as rule based systems and goes into much detail about how they can be used to solve real world problems. Also, many examples are given to demonstrate some uses of rule base systems. He does, however, spend most of the book on artificial intelligence as a whole, which makes this book valuable if knowledge about the entire field is sought.

Schuller, Slusher, and Morgan [3] developed an expert system for trouble shooting grain combine performance. This system incorporated speech synthesis to respond to the user. This system is a very good example of the application of expert systems to Agricultural Engineering. The system was developed to help operators, in remote locations, that could not otherwise obtain the expertise to solve some problems with there grain combines systems. The software was implemented in MULISP on both Compaq and TI microcomputers. Additional hardware was developed to provide the speech synthesis and was successfully implemented. This system illustrates the use of expert systems in Agricultural Engineering in that it is a problem that could not otherwise have been solved.

Whittaker, Thieme, Jones, and Barrett [4] give an introduction to expert systems that covers where they are appropriate, how to gather the knowledge needed, defining the problem properly, selecting an expert system development tool, encoding the knowledge, and testing the expert system after completion. The coverage of how to select the right tool for a problem is informative, and covers several different tools as well as giving a comparison between microcomputer- based software verses LISP-machine based systems. They discuss the advantages and disadvantages of both types of systems and give examples of both. Also, the applications of expert systems to agriculture is discussed and some suggestions for areas of work are given.

Barrett, Morrison, and Huggins [5] give a brief background of artificial intelligence and a summary of a study which identified the potential uses of artificial intelligence in agriculture. This summary is divided into the following areas: state of the art, predictions of the experts, potential agricultural applications, and the potential benefits of using artificial intelligence. They concluded that the areas of robotics, natural language interfacing, and expert systems could be the most beneficial to the future of agriculture.

Gaultney [6] discusses the potential for expert systems in agricultural system management. He concludes that expert systems are useful in many decisions involving agricultural systems, but care should be taken in selecting what problems to apply the expert systems to. He states "Problems which are complex enough to require an expert, solvable by no available algorithm, and constantly changing as new information becomes known, are good candidates for consideration by expert systems." He gives examples of areas that he feels expert systems are likely to be used in agriculture and goes on to predict what might might be achieved in agriculture by using expert systems in the future.

Drive line Investigations:

Schrock, Matteson, and Thompson [7] discus the development of a microcomputer based gear selection aid for agricultural tractors. This gear selection aid involved the estimation of fuel flow at the present operating conditions, and the prediction of fuel flow at a higher gear and a lower throttle setting. The two predictions were then compared to see if a significant amount of fuel could be saved by changing gears. If changing gears would save significant fuel, the suggested settings were displayed to the operator. The calculations were based on engine rpm, transmission rpm, and rack position readings. This work was pursued further by Blumanhourst [8]. Blumanhourst evaluated the performance of the gear selection aid and concluded that the average fuel savings was about 12%. He also conducted simulation work to investigate the effects of various parameters on the fuel consumption.

Rutkowski [9] reported the development of a similar device from Ford Tractor Operations. This device had gauges for fuel consumption and efficiency as well as lights to indicate gear up and throttle down changes the operator should make. He concluded that user reaction was overall favorable to this device and that sometime in the future such a device might be used to aid in the automatic control of drive line to achieve maximum efficiency.

Ibrahim [10] conducted work on the closed loop control of hydrostatic drive farm tractors. His work focused on developing an automatic control system to optimize the performance of a hydrostatic drive line. This involved engine and cost considerations to arrive at set points for operation. These "set points" were said to be the optimum operating conditions in that region. Overall, his work points out the method of development of such a control system and gives a good literature review of this area. This work along with others in this area show the usefulness of automatic control systems in helping the performance of an agricultural drive line.

It should be noted that the works mentioned above contain many good references and are good sources of information for further investigation.

CHAPTER THREE

INTRODUCTION TO EXPERT SYSTEMS

Before continuing with the explanation of the system to be developed to help find the speed of tillage, a short introduction to expert systems is necessary. This introduction will expose the reader to some of the common terms encountered when dealing with expert systems as well as some basic concepts involved in expert system development. Refer to appendix B for a glossary of terms commonly used in artificial intelligence.

Depending upon the author, there is a wide range of definitions of an expert system. Here we will consider it to be any system which uses rules of thumb to solve problems in much the same manner as human reasoning would. The purpose of an expert system is then to imitate the human reasoning process by making sound decisions, even if not all the information is available.

It is the job of the knowledge engineer to make sure that enough knowledge is included in the expert system to make decisions even if incomplete information is provided by the user. The knowledge engineer gets this information from an expert in the task domain of the expert system he is developing. As an example, the expert system MYCIN contains expertise of doctors about bacterial infections in the blood and inflammations of the membranes that envelop the brain and spinal cord. This was the first large expert system developed that could perform at a level equivalent to human experts in the area. This level of performance is largely due to the work of the knowledge engineers and their work with expert doctors.

Besides working with the experts, it is the job of the knowledge engineer to organize the knowledge into a knowledge base. He does this by translating the human knowledge into the concise rules of the knowledge base. The knowledge base is made up of rules of thumb, sets, values, facts, hypothesis, goals and/or assumptions that make up the expertise to be used by the expert system. The knowledge base is of use only after the knowledge engineer uses some form of development tool to organize it into an expert system. These development tools are sometimes referred to as expert system shells or environments.

An expert system environment usually contains facilities to interact with the knowledge engineer in a way that he might make the knowledge base into an expert system, usable by the end user. These shells usually also contain a declarative language, like LISP or PROLOG, used by the knowledge engineer to enter the knowledge base. Most environments use a specific control strategy of the decision making process. This is termed the inferencing method of the expert system shell. The two most common inferencing methods are backward chaining and forward chaining.

Backward chaining is a control strategy for which the goal of the expert system is known and the system searches for evidence to support or refute the achievement of that goal. Backward chaining works well in many real life situations because we often know what it is we believe, but have to provide supportive evidence in order to convince others of our beliefs.

Forward chaining , on the other hand, works more like a detective trying to solve a crime. The forward chaining expert system gathers available information about the task and attempts to deduce a conclusion based on that evidence and predetermined rules. Backward chaining and forward chaining both try to derive some conclusion about the information given in the task domain. They are both a part of the inference engine of the expert system.

The inference engine of an expert system is the driving force behind the system. It includes the rules and structure of the knowledge base and, in conjunction with the information obtained from the user, derives or infers new conclusions about the current situation. The knowledge engineer is sometimes only given very limited control over the inference engine of the system, but is generally somewhat responsible for its development. It is therefore his responsibility to ensure that the inferencing mechanism of the expert system manipulates the goals, facts, and rules in such a way as to arrive at the correct conclusions.

The goals of the system must be some achievable result of a line of reasoning. This could be as simple as stating "The problem is solved." or as specific as "The animal is a red winged blackbird." The goals may also be used to narrow down the possible conclusions, and then require that subgoals be achieved. The following is an example of goals and subgoals used to identify animals.

```
                          |---> 1. The animal is a mammal
                          |
                          |  |-----> 1.1 The mammal is a cat
                          |  |
GOALS --------------------|  |-----> 1.2 The mammal is a dog
                          |  |
                          |--|-> 2. The animal is a reptile
SUBGOALS --------------------|
                             |-----> 2.1 The reptile is a snake
                             |
                             |-----> 2.2 The reptile is a lizard
```

Figure One. Goal and Subgoal example.

If the expert system backward chained, it would attempt to find evidence as to whether the animal is a mammal or a reptile. After finding this evidence, it would try to find out the type of mammal or reptile it was finding. For instance, if the system determined that the animal was a mammal, it would then try to find evidence to support that the mammal is a dog or to support that it is a cat. This is a method of backward chaining to limit the number of rules and facts that must be evaluated in order to reach a sound conclusion.

Facts are generally a parameter, or variable that is somehow manipulated by the knowledge base. Facts may be in the form of numeric values, object-attribute pairs, string assignments, or true-false information. An object-attribute pair obviously consists of an object and an attribute and some relationship between them. An object is usually considered to be something with which some characteristic can be associated. An example of this type of object would be "the weather today". This could take on the characteristics or attributes of such things as "good, bad, ok, rainy, clear, etc...." As can be seen from this example, the object does not need to be a physical thing and the attributes are not only physical characteristics of the object. By definition the facts are manipulated by the knowledge base. This occurs within the rule of the system.

The rules of the knowledge base are usually considered to be condition-action pairs. This means that the rules most often follow the IF-THEN type of reasoning; IF this condition is true, THEN take this action. An example of a typical rule would be:

IF the reptile has no legs

THEN the reptile is a snake

The condition is that the reptile has no legs, and the action is to reach the conclusion that the reptile must be a snake. These type of rules may also have confidence factors associated with the conclusions. That is to say that the system might tell the user that it is 90% sure that the reptile is a snake if it has no legs. This allows the knowledge engineer some room for error when he is constructing the rule base for the expert system. It also can be useful when more than one conclusion can be reached with very closely related evidence.

The knowledge engineer must be careful, when he is developing the knowledge base for an expert system, to include all of the necessary information needed to make sound conclusions or at least he must display with what confidence he makes his conclusions. This will allow the end user to understand the expert system and how it may be reaching its conclusions.

Hopefully this brief explanation of some of the workings of expert systems will help the reader to answer questions that arise while continuing through this work. Further information is given appendix B, the glossary of terms, or in the references listed in the bibliography.

CHAPTER FOUR

APPLICATION OF EXPERT SYSTEMS TO THE SPEED OF TILLAGE

From the definitions of the types of inferencing strategies, it is clear that backward chaining should be used for this problem. We know what the goal is, i.e. what speed should the operator pull the given implement for the existing conditions. Backward chaining will be used to gather information until enough evidence is found to recommend a final speed. The information needed to find this conclusion will involve the operator, equipment, conditions, and operation. Also, some information about future work and weather must be included. Since not all the information is needed to reach some conclusions, the system must allow for recommendations about the speed within the inferencing rules. As an example, if the operator could not react at the speed the system tells him he should travel, he would need to slow down irregardless of other conditions. This ability can be included in the system by categorizing the rules and making conclusions after each category has been evaluated. The major rule categories needed for the determination of tillage speed are; the capability of the tractor and the operator, the quality of job performance, and the importance the operator places on the cost of his fuel, labor, and timeliness for the operation. Refer to appendix E for the semantic net of the system.

The capability of the tractor to perform the given operation is an important first step in the determination of the best speed for a tillage operation. If the tillage conditions, such as the desired depth of tillage, cannot possibly be met by the tractor on hand, then it is obvious that no speed will be optimum or even possible. The maximum draft for the given conditions will be calculated from the equations in the ASAE yearbook of standards [11]. In the future equations could be replaced by a simulation of the specific system and possibly load sensing equipment. This speed is clearly a function of the power that the tractor can produce and thus will be termed the "power limited speed" throughout the remainder of this paper.

It is possible, and probable for some operations, that the power limited speed could exceed the speed at which the operator feels he is safe, comfortable, and able to react. This possibility necessitates the inclusion of rules to assure that the user is capable of handling the equipment at the power limited speed and make adjustments if he cannot. These adjustments would also allow for his comfort and safety. The user of the expert system will be given a choice of traveling at the power limited speed or at a lower speed at which he is more comfortable. This lower speed will be termed "reaction speed".

It is also possible that the power limited speed and the reaction speed are too fast to achieve the quality of job performance he desires. The "quality speed" is that speed at which acceptable quality of job performance is achieved. The quality of the job performance must be assumed to be a subjective measurement by the operator. For instance, if the job is disking to control weed growth and the implement is being pulled at a speed too fast for adequate disk penetration, the operator would identify this and indicate a desire to slow down. This will be handled by asking the operator to enter his confidence he has that he is performing the job as well as he desires. This will allow for him to continue at the same speed if he is doing the job with a certain percentage of success, or it will slow him down if he is not succeeding that percentage of the time. It should be added that the three speed limits; power, reaction, and quality, do not have to occur in that order. That is, the job quality limit may be at a higher speed than the operator reaction limit which may be higher than the power limit.

Another area of interest is cost per acre of the tillage operation. This cost can be calculated from machinery management practices which break this cost into two main categories; fixed and variable costs. Fixed costs are items such as taxes, housing, and insurance. These costs are not included in the speed of tillage system because they are not speed related. Only variable costs, which are speed related are included in this system. Variable costs are divided into three areas; fuel, labor, and timeliness. These costs should affect the speed of tillage by the weight the operator places on them individually in the overall operation. If the operator considers fuel savings to be very important, but timeliness and the value of his labor are unimportant to him, he may be willing to sacrifice some speed to save fuel. On the other hand, if he needs to get a crop planted before the predicted future rain, he may be willing to disregard fuel savings to be timely with his planting. These considerations must be included in the rule base for the expert system to be effective in determining the optimum speed of tillage for given operations and conditions. To include such considerations, some questions will be asked and a weight will be associated with each of them. The total cost will then be calculated and the slope of the cost curve determined.

This chapter has been an overview, in general terms, of how the problem of tillage speed determination might be solved by the use of expert systems. The major categories and procedures of such a system have been outlined and briefly explained. The next step in the development of the expert system was to determine what development tool might be best suited to this problem. Several environments were tested and evaluated for this application; EXPERT-EASE, MICROPROLOG-APES, and INSIGHT2+. Of these, INSIGHT2+ proved to be the most suitable for this type of work and other in depth system development problems that use backward chaining.

CHAPTER FIVE

INTRODUCTION TO INSIGHT2+

INSIGHT2+ is an environment or tool for the development of expert systems, and has many desirable features. Some of these features are; the ability to compile, backward and forward chaining, interface to MS-DOS, links to conventional programming languages and data bases, inexpensive to purchase, built-in text and dbase editors, and the ability to "chain" and share information with other INSIGHT2+ knowledge bases. The advanced structure of INSIGHT2+ also allows for the concise control of the knowledge base throughout execution.

Typically, speed of execution has been one of the major drawbacks of using expert systems in all but the most necessary situations. INSIGHT2+ has overcome this problem by compiling the knowledge base for faster execution times. This along with the advanced structure of the knowledge base representation makes INSIGHT2+ a very usable system for the price. The knowledge base in INSIGHT2+ is divided into five key areas; fact declaration, control elements, goal outlining, rule base implementation, and textual information. INSIGHT2+ terms the development language it uses as Production Rule Language(PRL). The PRL is used to implement the five basic areas of structure. More detailed information on the PRL can be obtained in appendix C, the quick reference to INSIGHT2+.

Fact declarations are PRL statements to declare what type a fact or variable is. The possible fact types in INSIGHT2+ are; numeric, object (object-attribute pairs), string, and simplefact (true-false information). These parameters may be initialized, forgotten, or reinitialized as the knowledge base is being executed.

Control elements consist of reserved words that in some way control the execution of the knowledge base. As an example, MULTI assigns that a fact could have more than one value at the same time. At execution time the user will be prompted to enter all valid conditions of the fact. These statements help the knowledge engineer control how the user can interact with the expert system at run time.

INSIGHT2+ implements the goals of the knowledge base as in figure one in chapter three, using backward chaining. The speed of tillage system will have only one goal; to find the most desirable final speed of travel for the given tillage operation and conditions. This goal will be achieved by the querying of the user for observable information as well as his personal feelings about the situation. This information will be processed to find an acceptable final speed and will satisfy the goal.

The rule base in INSIGHT2+ is implemented in the IF-THEN-ELSE form and may contain conjunctive (AND) or disjunctive (OR) operators in any one of the three main elements. This aids in the control over the conclusions made by the system. The ease of use of this feature is one of the most desirable features of INSIGHT2+. These rules are easily driven by one rule that requires the desired conclusions from all others as the conditional elements, and the goal as its action.

The conclusions, questions, and explanation given by the INSIGHT2+ system at run time are the last item included in the structure, except the END statement. The questions to be used are called by the ASK statements in the rule base of the expert system. This will display the question and prompt the user for answers. If the knowledge engineer does not use the ASK statements, INSIGHT2+ will prompt the user, in a crude way, for answers to the appropriate questions as needed. At this time the F5 function key display will be highlighted at the bottom of the screen with EXPL and will give explanation of the question to the user, if the knowledge engineer has provided any. After the question has been answered, the value will be entered into the rule base and used to reach some conclusion. This conclusion can then be displayed by the system in one of two ways. The system can display conclusions in the form of true elements of THEN actions found in the knowledge base. If the knowledge engineer choses not to let the system do this, he may use the DISPLAY commands to show conclusions in whatever manner he desires. In all three types of text, fact values can included to give the system an appearance of intelligence. These text features also simplify the use of the system for the end user by offering him more information about questions and conclusions.

The above mentioned functions contributed greatly to the choice of INSIGHT2+ as the expert system tool to be used to develop a speed of tillage expert system. In addition, it seems to be well suited to problems of this nature in general. INSIGHT2+ is well structured, easy to use, readily available, and inexpensive as well as capable of intimate user interaction. These features are all considerations when chosing an expert system environment to work in. In particular, the capability of the system to interact with the user is very important in problems which the user must make observations in order for the system to reach conclusions. This type of problem is common in engineering applications, and is exactly what the speed of tillage problem is. INSIGHT2+ runs on an IBM PC or compatible system and requires a hard disk, and 512k of memory to be effective.

CHAPTER SIX

DETERMINATION OF EXPERT SYSTEMS NEEDS FOR IMPLEMENTATION

After INSIGHT2+ was chosen to implement the speed of tillage expert system, decisions about exactly what was to be included in the system had to be made. The first decision was to decide what assumptions would be appropriate. Next, equations to be used had to be derived so that the proper calculations could be made. In the process of finding the two above mentioned items, the questions to be asked of the user had to be determined. This chapter will be dedicated to the explanation of the assumptions, equations, and information needed to implement the speed of tillage expert system using the INSIGHT2+ development tool.

The first and most important assumption of the system is that only six tillage jobs will be included in the expert system. These six jobs are; plowing, cultivating, disking, planting, drilling, and rotary hoeing. Most other assumptions were made due to the nature of the information provided in the ASAE standard for the agricultural machinery management data [11]. This indicates that we have assumed that the equations for machinery management information given in the ASAE standards are correct for the operations that are being performed. This assumption may not be true, but this is the best possible source of data and equations available at this time. In the future, equations and data may exist that are more appropriate for the given jobs and conditions.

It was assumed that working conditions allow the operator to achieve the job quality he desires. The soil is assumed to be dry, unworked, and tillable. The draft calculations do not include any forces other than the horizontal force required to pull the implement. This means that the rolling resistance of the transport wheels has been neglected as well as any vertical or side forces on the implement. The following is a table of the assumed quantities of each operation;

OPERATION	SOIL TYPE	EFFICIENCY TRACTIVE	FIELD	OTHER ASSUMPTIONS
Plowing	silty clay	70%	70%	Highspeed mold-boards, coulters, and landsides
Cultivating	not given	60%	80%	Row cultivation
Planting	not given	55%	70%	Seeding, with fertilizer and/or herbicide.
Drilling	not given	55%	75%	Deep furrow drill
Rotary hoeing	not given	55%	80%	-------
Disking	clay	60%	75%	-------

Table one. Assumptions about operating conditions.

After these assumptions were made it was possible to find appropriate equations for draft for each operation. These equations are;

OPERATION	DRAFT IN POUNDS
Plowing	$(7 + (0.09*speed^2))*width*12$ in/ft*depth
Cultivating	30*depth*width
Planting	300lb/row = 300*12in/ft*width/(row spacing)
Drilling	80lb/opener = 80*12in/ft*width/(opener spacing)
Rotary hoeing	(30 + 2.4*speed)*width
Disking	1.5*mass = 1.5*weight

Table two. Equations used to calculate operation draft.

Definitions (units):

speed	= travel speed (mph)
width	= implement width (feet)
depth	= implement depth (inches)
row spacing	= planter row spacing (inches)
opener spacing	= drill opener spacing (inches)
weight	= disk weight (pounds)
draft	= horizontal draft (pounds)

Other miscellaneous equations used:

Fuel consumption;

$$\text{diesel fuel} = (0.52*hpr) + 0.77 - (0.04*((738*hpr)+173)^{1/2})$$

$$\text{gasoline} = (0.54*hpr) + 0.62 - (0.04*(697*hpr)^{1/2})$$

Acres/hour;

$$ac/hr = \frac{width*speed*field\ eff*5280}{43560}$$

Dollars per acre;

$$fuel\ \$/ac = \frac{fuel\ consumption*hpreq*fuel\ price}{ac/hr*tractive\ eff}$$

$$labor\ \$/ac = \frac{labor\ cost}{ac/hr}$$

$$timeliness\ \$/ac = \frac{k*crop\ value*area}{ac/hr*24hr/day*2}$$

Total cost per acre = fuel + labor + timeliness costs

Definitions (units):

fuel consumption	= fuel used (gal/(hp-hr))
hpr	= horsepower ratio = $\frac{hp\ required}{hp\ available}$
fuel price	= \$/gal of fuel
field eff	= field efficiency (%)
crop value	= the gross value of the crop associated with this tillage operation (\$/ac).
area	= the area of land the associated crop will cover (acres).
hpreq	= the horsepower required by the given job
k	= timeliness coefficient, per day

Some assumptions were made about the operator and his abilities. These assumptions are that he can judge the job quality, weather today and tomorrow, the importance of this job, and his own personal priorities. Also, it is assumed that he has been trained in the use of the INSIGHT2+ user environment. This is a key point in that if he has not been trained, at least minimally, he will not know what the function keys are used for during execution.

As the assumptions were made and the equations chosen, the questions the user needed to answer for the speed of tillage expert system became clear. From the above section it can be seen that the user needs to enter the following items;

PTO power of the tractor

Tillage operation in progress

Implement width

Planter row spacing (if appropriate)

Drill opener spacing (if appropriate)

Disk weight (if appropriate)

If he can react at the recommended horse power limited speed. If not then ask what speed he can react at.

Fuel price

Crop value

Labor cost

Area of land to cover

Fuel type

Confidence about good weather today
(to adjust timeliness cost)

Confidence about good weather in the future
(to adjust timeliness cost)

Confidence that he is delaying some other operation
(to adjust timeliness cost)

Confidence that he has personal matters of higher priority
(to adjust labor cost)

Confidence that he is performing the job as well as he desires
(to adjust speed if necessary)

CHAPTER SEVEN

PROJECT IMPLEMENTATION IN INSIGHT2+

This chapter will cover the implementation of the speed of tillage expert system in INSIGHT2+. It will not, however, cover the exact syntax used. It will instead, cover the system in general terms of the INSIGHT2+ implementation. This chapter will deal with the rule base of the system and the conclusions found while execution occurs. In doing this, the inputs needed from the user will be covered and their purposes explained when appropriate. The reader should consult appendix A for the exact implementation of the speed of tillage expert system in INSIGHT2+.

The rule base of the system, as discussed in this chapter, is only the actual rules used to reach conclusions and goals, and does not include the surrounding control elements or declarations. The first rule, in this case, is the most important rule of the system. It provides the driving force behind the knowledge base that attempts to achieve the goal of the system. Any backward chaining system with only one goal needs to have a rule similar to this one. In the speed of tillage rule base this rule has been termed the rule to do the evaluation of speed. The conditions of this rule are the conclusions of all the other rules in the system, the conclusion of the driving rule is the goal of the system. Additional conclusions are included to force the system to cycle once a final speed is determined so that if conditions change that affect the quality of work, the operator can let the system know and an appropriate speed change can take place. There is no ELSE element of this rule because it cannot fail. This is accomplished by constructing the other rules in such a way as to force them to continue until the desired conclusion is found. This can even include the restart of the system, but generally only requires some input by the user. The remaining rules of the system will be described in the order they are fired by the driving rule.

The first conclusion that must be met is that the speed may be evaluated. The rule to do this simply displays the beginning informational text and waits for the user to continue when he is ready.

The second conclusion to be met is that the PTO power, job (or tillage operation) and implement width are set. All three of these items must be supplied by the operator. The system asks the operator to enter the PTO power of the tractor, the tillage operation he is performing, and the width of the implement he is pulling. These values are then entered into the knowledge base and used until changed by a restart of the system. These values must be known in order to perform the needed calculations later in the system.

The third condition is that the depth is set. This rule finds the depth that the implement is being pulled. If the implement is not the plow or cultivator, a depth of two inches is assumed since it does not come into consideration in the draft calculations. This assumption is only to give depth some value, not for any other calculations.

The fourth condition is that the power limited speed is found. This is a series of six rules (one for each job) that find the maximum speed this horsepower tractor can pull the given implement at the given depth. The rule for plowing is unique in that it performs an iteration to find this speed. This was due to the complexity of the equation for maximum speed of plowing as it related to draft. The planting rule contains a question to obtain the row spacing form the operator. This is to calculate the number of rows being planted since this is related to draft. A similar question is asked to find the opener spacing for the drill. This is also because draft is related to the number of drill openers or rows. The weight of the disk is asked in the disking rule because draft is only related to the weight of the disk. Once the power limited speed has been found, the system will continue to the next rule.

The next rule sets the speed to fifteen miles per hour if the power limited speed was greater than this. This is not uncommon on such operations as rotary hoeing, which requires little power. The rule after this checks to see if the operator can react at the power limited speed or fifteen miles per hour, which ever is the smallest. If the operator cannot react at this speed he is asked to enter a speed at which he can react. This rule includes not only reaction time, but operator comfort and safety as well.

The eighth condition to be met is that the draft required to do the job is set. It is necessary to recalculate the draft, which was indirectly found in the power calculations, because of execution methods used later. The eighth condition is satisfied by a set of six rules that calculate the draft required for the given job. Some other constants are also assigned in these rules. These constants are; field efficiency, drawbar power, and the timeliness coefficient. The range of possible speeds for the given operation is also checked in these rules. If the operator is outside of the appropriate range, he will be informed so and given the opportunity to adjust his speed accordingly.

The next rule simply asks the user for price information. The user is asked the type and current price of his fuel, labor, and the value of his crop. He is also asked how much land he is going to cover that is associated with the crop of the value he entered. This information must be known to calculate the cost per acre of his operation.

The next four conditions are used to calculate the cost per acre of the operation at the current speed. These rules calculate the horsepower ratio, fuel consumption, and arrive at some current cost of fuel, labor, and timeliness on a per acre basis.

The next rule is a very important one. It asks the user about factors that affect his labor and timeliness costs. The questions asked are;

Is the weather good today?

Is the weather forecast good?

Are you delaying other important operations by performing the present one?

Are there any personal matters that are of higher priority than this operation?

The user is asked to enter his confidence about his answers to these questions. This allows the system to adjust the value of labor and timeliness costs by some proportion to how confident the operator is that the above questions are true. This is done by assigning some gain to the costs. The gain for labor is termed klabor and is equal to;

1 + 0.005 * user confidence that he has other priorities

The gain associated with timeliness is termed ktime and is equal to;

```
1 + 0.002 * (100 - user confidence
             that the weather is good
             today)

  + 0.002 * (100 - user confidence
             that the weather forecast
             is good)

  + 0.002 * user confidence that by
            performing this operation
            he is delaying some other
            important operation.
```

These gains are later multiplied by the appropriate cost before that cost is used in the total cost calculations.

The fifteenth condition that must be met is that the quality of work has been checked and speed has been adjusted if it is not adequate. This is done by asking the user to enter his confidence that the quality of work he is doing is adequate. If he responds that the quality of work is at least sixty percent adequate, no adjustment is made. If, on the other hand, he responds that the quality of work is less than sixty percent adequate, the speed is adjusted by the following equation;

```
speed = speed - 0.009 * (100 - user confidence
                         that the quality of
                         work is adequate)
```

This allows the system to slow the tractor by some amount that is proportional to the lack of confidence the user has in the quality of work he is performing. If the user is zero percent sure that the quality of work is adequate, the system will slow him nine tenths of a mile per hour and recalculate the costs involved in doing the operation at that speed and ask the user if he is doing the desired job at this speed. Other confidence values less than sixty percent would affect the speed proportionally and perform the same operations. When the user is confident that he is doing a good job, he will continue to the next rule.

The last four rules of the rule base make sure the fuel is not costing the operator more than he is willing to pay on a per acre basis. They do this by first calculating the total cost, including the gains of labor and timeliness, at the present speed. The speed is then decremented by one tenth of a mile per hour and the total cost is recalculated. If fuel is costing significantly more than the labor and the timeliness combined, the slope of the cost curve will be positive going from the lower speed to the greater speed. This is because fuel tends to cost more per acre with increased speed, while labor and timeliness tend to cost less. If the slope of the total cost is positive the speed will be decremented by one tenth again and the slope recalculated until the slope is negative. When this point is reached point one is added back to the speed, thus setting it closer to the speed with a zero slope cost curve. This would then be the speed the system would recommend to the user as the most desirable speed. If the slope of the line is negative on the first iteration, all of the conditions are met to satisfy the driving rule which then displays the recommended speed to the user and states that the speed has been adjusted accordingly. This is assuming that some mechanism is in use to allow for the automatic adjustment of speed.

After the final speed of tillage is recommended to the user, the system will forget some of the calculations it has performed and cycle through again. This time the user will not be asked any of the questions except about job quality. This is due to the fact that it is assumed that the user is still on the same tractor, doing the same job, and has learned nothing new about labor or timeliness considerations. It does, however, allow for changing field conditions that might cause changes is job quality.

The preceding chapter has covered how the speed of tillage expert system was implemented using INSIGHT2+. The rule base was covered in depth but the actual syntax of the system is found in appendix A. A quick reference to INSIGHT2+ is provided in appendix C and should be consulted for further questions about syntax and function of INSIGHT2+ commands.

CHAPTER EIGHT

HOW TO USE THE SPEED OF TILLAGE EXPERT SYSTEM

This chapter will cover the use of the speed of tillage expert system as written in INSIGHT2+. This description will only take one route through the expert system and cannot be considered comprehensive. Additionally, it has been assumed that the reader can refer to appendix C (INSIGHT2+ quick reference) at any time to answer questions about specific terms and function key assignments.

The user could have the INSIGHT2+ system installed as described in the manuals that come with the software and follow along with the tutorial. If the reader does not have access to the INSIGHT2+ system he can get an appreciation for how the system works and what is involved. If the reader is not actually using the system, he should refer to appendix D (example run of the system) for details of how information is displayed and how questions are asked. Some knowledge of how to run INSIGHT2+ is assumed if the reader is actually using the system, such as start up and compiling and loading the knowledge base to executed. It is assumed that if the reader is using the system, that he has a copy of the speed of tillage expert system. If he does not, one is provided in appendix A and could be entered using the editor provided with the INSIGHT2+ package. It should be noted that the function keys will be termed F(number of function key) (highlighted term for key), which is now the INSIGHT2+ system displays the current value of the function keys. It should also be noted that the F3 STRT key will start the program completely over at any time. Now, assuming that the user has the system on line, compiled, and ready to start, or that the reader is ready to continue, the demonstration of the speed of tillage expert system will begin.

Upon start up of the system, a message is displayed to press the F3 STRT key to begin execution. A screen of text then appears showing the title and author of the system. Press F1 PAGE to continue. Text is now displayed describing the purpose and intent of the system. Press the F2 CONT key to continue.

It should be noted that the example used here is somewhat unrealistic, and was chosen to illustrate some of the features of the knowledge base such as the iteration to determine the speed at which fuel costs are acceptable. Also, the rules in this tutorial are presented in the same order as they appear in the program. Refer to appendix A, program listing, to view the exact rules.

The first question the system asks is: Please enter the PTO power of the tractor you are operating; and the user is prompted to enter a numerical value, enter 250 and press return. Next the user is asked which one of the six tillage operations he is performing. The space bar or the arrow keys will change which operation is pointed to for selection. Position the pointer to Plowing and hit return. The user is now asked to enter the width of the implement in feet, enter 6, return. Since plowing was entered as the tillage operation, the system will prompt the user for the depth the implement is being pulled, in inches. Enter 6, return. The user would have been asked to enter the depth if the job was cultivating also, since the draft is dependent on the depth of tillage for both operations.

The system will now iterate to find the maximum speed that 250 hp tractor can pull a six foot plow six inches deep. After arriving at this speed the system will make sure that it is not over 15 mph, if this speed is greater than 15 mph it will be adjusted to 15 mph and continue. The system now asks the user if he is comfortable, safe, and can react at the speed it has found as the maximum operable speed. The system will display that it has found 9.7 mph to be the power limited speed.

The reaction question is posed as a true-false question. The selection of TRUE or FALSE is made by depressing the space bar until the appropriate value is highlighted and then pressing return. Enter FALSE at this point. The user is now prompted to enter a speed that he is comfortable with and can adequately react at. Please enter 9. Now the draft required to pull the six foot plow at nine miles per hour, six inches deep is calculated. Also the values of k, tractive and field efficiency, and drawbar power are set.

The user is now prompted to enter the current fuel price (enter 2) in $/gal, the estimated value of the crop that this tillage operation affects (enter 10) in $/acre, the cost of his labor (enter 0.1) in $/hr, and the area of land that this operation will be performed on that is associated with the crop entered above (enter 100) in acres. This information will be used in the calculations of fuel, labor, and timeliness by the system. Next, the system will ask the user to enter the type of fuel he is using, please enter diesel. Calculations to find the cost of fuel, labor, and timeliness at nine mile per hour, on a $/acre basis, are now performed.

Now that the system has a cost of all three consideration calculated, it will adjust these values according to the importance the user places on them. The user will be asked four questions that affect the cost of his timeliness and labor. In each question he will be asked to enter his confidence that the answer is true, and a confidence bar will be displayed on the screen. The user can adjust his confidence by using the space bar or the arrow keys as described in the first question and in the explanations of the other three. The user must depress the return key to enter his confidence after adjusting it. The four questions are; is the weather good for plowing today (enter 100), is the weather forecast good for plowing (enter 100), is he delaying any other vital operation while plowing (enter 0), and are there any personal matters of greater priority than plowing (enter 0). After this is completed the system will assign gains to the cost of labor and timeliness, which will be used in the total cost calculations to weight these costs heavier than they would have normally been.

The system will now attempt to determine if the job quality is as desired by the operator. He will be prompted to enter his confidence that the job quality is good (enter 70). If his confidence is less than or equal to 60 percent, the system will adjust his speed in proportion to the lack of confidence he has. The user will be prompted again for the his confidence about the job quality until he is more than 60 percent confident that he is doing the desired job. Since 70 was entered, the system will not adjust the speed of tillage from nine miles per hour.

The total cost is now calculated and a check is made to see if fuel is costing the operator more than he is willing to pay on a $/acre basis. His willingness to pay for fuel is based on the values he has placed on fuel, labor, and timeliness as entered into the expert system. Since the cost of timeliness and labor generally go down with increased speed and the cost of fuel goes up, if the slope the the three combined costs is positive fuel must be costing significantly more than labor and timeliness combined. The system checks to see if this is occurring done by decrementing the speed of tillage by 0.1 mile per hour and recalculating the total cost, including the gains for labor and timeliness. The slope of the line between this cost and the original cost is determined. If this slope is positive or zero, the system iterates again. In this example the slope of the cost between 8.9 and 9.0 mph is positive, so the current cost is adjusted to that at 8.9 mph and the cost at 8.8 mph is calculated. The slope between these speeds is calculated and checked for non-negativeness. In this example the slope is non-negative until the cost between 7.6 and 7.7 mph. One tenth is then added back onto the speed since the cost at 7.7 mph must be less than that at 7.6 mph for the slope to be negative. After these calculations are completed, the system will display the speed it has found to be the "best" to operate at along with the costs associated with operating at this speed.

The user now has the choice of cycling through the system again, assuming all the same conditions except the job quality which could vary with soil type, texture, moisture, ... or he may choose to start completely over again, erasing all values previously entered or calculated. He can also exit the system at this time.

Hopefully the reader has now gained an appreciation for how the speed of tillage expert system operates and will better understand how expert systems can be used to solve actual problems in engineering. This tutorial description has only covered one possible path of execution, others can be seen in appendix D and should be consulted to gain a greater understanding of how the system works in other tillage operations.

CHAPTER NINE

CONCLUSIONS

Program Performance

The speed of tillage expert system performed well for the situations that it was intended to handle. In all of the given situations the program did complete the tasks, with acceptable performance. In the example given in the chapter eight, the system found that when a large tractor was being operated with a small plow, expensive fuel, cheap labor, and a low timeliness cost that fuel consumption was a major factor in the the total cost per acre of the tillage operation. The system then recommended an appropriate speed to pull the implement. This is just one case of how the system performed, other cases would be situations that might arise in actual tillage operations.

Only one real problem is evident with the system. This is its inflexibility. It is difficult to add new tillage operations to the system and thus confines analysis to the six operations defined for use. The user can however chose the tillage operation that is closest to what he is doing and get some idea of what speed to travel. This problem could be overcome if some additional information were available to the expert system at run time. This information would probably be available if the system were used with the drive line optimization device.

One of the objectives of this project was to determine if it would be possible to find the desired speed of travel for input into a closed loop drive line optimization device. The results show that it would be possible if devices existed to measure the inputs need, on the go, for the expert system. Some of these inputs would be job quality, weather conditions, and the delay of other, more vital jobs. This might point the direction that future work might be appropriate.

Possible Future Areas of Work

Several areas for future work have become evident during the evolution of the speed of tillage expert system. The most obvious is the inclusion of drive line simulation models for the determination of fuel consumption and other system parameters. This along with the additional inclusion of ground speed and load sensing devices would allow the automation of many of the inputs needed by this system. If other sensors could be developed to gather less exact information about the job and conditions, the system could perhaps someday operate nearly independently of human operators.

Another area that valuable work could be done in is improvements in the flexibility of the program. The development and addition of sensing equipment would help make the system more flexible, but some work needs to be done in the area of predicting timeliness coefficients for specific jobs and times. The present flexibility problem is the result of the lack of available information needed to provide more flexibility. Also, the present system was meant to be only an aid to the tractor operator, not a controller.

In addition to the above mentioned areas of future work, this project as opened the door for many areas of work using expert systems in Agricultural Engineering. It has shown that it is possible to solve problems that are not procedural in nature and problems that need human observations to be solved.

Summary

Expert systems are computer programs that emulate human expertise in a given task domain. An expert system has been developed to aid the tractor operator in the choice of proper tillage speed for several operations under varying conditions. This system is called the speed of tillage expert system and resulted from research involving the optimization of agricultural drive lines, using a closed loop automatic control system. This expert system was intended to show that it would be possible to implement such an idea to further automate the agricultural vehicle. Some restrictions resulted from the implementation of this system for this project. These restrictions included the need to use the ASAE standards [11] on machinery management practices instead of the simulation of real systems. This could have made some of the results of the system inaccurate or false. Also, because of time limitations, the system was developed in a manner which does not allow for the easy addition of other tillage operations. Both of these restrictions would need to be corrected if a full scale implementation of the system were attempted. This investigation was however a success in several respects.

The expert system that resulted from the investigation of the "best" speed to pull specific tillage implements under given conditions has proven to be quite useful in at several respects. First, this expert system will provide an example for others to use when developing expert systems with INSIGHT2+. This will allow future users of INSIGHT2+ to learn the system more quickly and to understand it better. Second, the system has opened the possibility for future work in the automation of agricultural drive lines. This expert system could be linked with a drive line optimization device to control the speed of tillage operations as well as optimize drive line performance. Third, the system could give tractor operators a chance to hypothesize certain situations and observe the resulting costs incurred at specific speeds of operation. This might help educate farmers in the choice of tillage speed , even if the expert system were not installed in a tractor. Last, the development of the speed of tillage expert system has given light to the fact that expert systems can be successfully applied to Agricultural Engineering problems. Over all, this project has been a success and has provided valuable knowledge in the area of expert system development.

REFERENCES

[1] Harmon P. and King, D., **Expert Systems for Business**. John Wiley & Sons Publishing Co., 1985.

[2] Winston, P.H., **Artificial Intelligence**. Addison -Wesley Publishing Co., Reading, MA., 1977.

[3] Schuller J.K., Slusher R.M., and Morgan, S.M., An Expert System with Speech Synthesis for Troublesnooting Grain Combine Performance. TRANSACTIONS of the ASAE, 29(2):342-344, 350, ASAE, St. Joseph, MI. 49085-9659.

[4] Whittaker A.D., Thieme R.H., Jones D.D, and Barrett, J.R., Creating Expert Systems. Preceedings of the Agri-Mation2 Conference, ASAE, St. Joseph, MI. 49085-9659.

[5] Barrett J.R., Morrison J.B., and Huggins, L.F., Artificial Intelligence and Expert Systems in Agricultural Research and Education. ASAE Paper No. 85-5516, ASAE, St. Joseph, MI. 49085-9659.

[6] Gaultney, L.D., The Potential for Expert Systems in Agricultural Systems Management. ASAE Paper No. 85-5033, ASAE, St. Joseph, MI. 49085-9659

[7] Schrock M.D., Matteson D.K., and Thompson, J.G., A Gear Selection Aid for Agricultural Tractors. ASAE Paper No. 82-5515, ASAE, St. Joseph, MI.

[8] Blumanhourst, M.B. 1984. Evaluation of a Gear Selection Aid for Fuel Efficient Tractor Operation. Unpublisned M.S. Thesis. Kansas State Univ. Library. Manhattan, KS. 66506.

[9] Rutkowski, D.J., Development of a Fuel Efficiency Monitoring Device by Ford Tractor Operations. SAE Paper No. 851594, SAE, Warrendale, PA. 15096.

[10] Iorahim, B. 1975. Closed Loop Control of Hydrostatic Drive Tractors. Unpublished Dissertation. Kansas State Univ. Library. Manhattan, KS. 66506.

[11] American Society of Agricultural Engineers. Agricultural Engineers Yearbook of Standards, ASAE, St. Joseph, MI. 49085-9659.

APPENDIX A
SPEED OF TILLAGE INSIGHT2+ LISTING

This listing has been modified to fit the margin requirements for thesis submission. If the reader is entering this knowledge base for execution, he should use 80 column lines. Places where lines are broken but would fit on 80 column the user should enter as one line. The TEXTS, DISPLAYS, and EXPANDS should be fixed to look as good as possible at execution.

```
TITLE  SPeed Of Tillage  S.P.O.T DISPLAY

MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
[[[[111111000000000 S T A R T  U P 000000000111111[[[[
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM

MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
11111222[[[ Press F3 STRT to start the system [[[2221111
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM


!             ------------------------
!       The following are the fact declarations.
!             ------------------------
NUMERIC maximum operating speed ! in mph
AND     max op speedone         ! recalculated max speed
AND     draft required          ! in pounds
AND     field efficiency        ! from ASAE yearbook
AND     tractive efficiency     ! from ASAE
AND     k                ! k is the timeliness coefficient
AND     fuel consumption        ! this is in gal/(hp-hr)
AND     implement width         ! in feet
AND     hprequired              ! power required (hp)
AND     hpratio  ! ratio, power required/power available
AND     ac                      ! acres per hour
AND     fuel                    ! the cost of fuel, $/acre
AND     weight     ! the weight of the implement, pounds
AND     row space       ! row spacing on planter, inches
AND     opener space  ! opener spacing on drill, inches
AND     fuel price     ! the current fuel price,$/gallon
AND     depth       ! the depth of the implement, inches
AND     crop value       ! the value of the crop, $/acre
AND     labor cost        ! the cost of your labor, $/hr
AND     area  ! the area of land you are going to cover
!                        for the crop value given above
AND     time                     ! the timeliness cost, $/acre
AND     labor                      ! the labor cost, $/acre
AND     total                      ! total cost, $/acre
AND     total1 ! recalculated total cost at 0.1 mph less
AND     plowing max      ! maximum speeds for the various
AND     planting max     ! jobs. They are preset to begin
AND     drilling max     ! with for the table display. If
AND     discing max      ! it is the correct job, the max
AND     cultivating max ! speed is recalculated.
AND     draft1  ! the draft at 0.5 mph less than present
!                speed. This is used to find plowing max
AND     ktime         ! this is the "weight" for timeliness
AND     klabor        ! this is the "weight" given to labor
```

```
AND     rise  ! the rise of the cost curve to check cost
AND     power  ! the available drawbar power of tractor
AND     ptopower    ! the available pto power of tractor
AND     labor one          ! the labor cost times klabor
AND     time one       ! the timeliness cost times ktime

SIMPLEFACT react            ! asks if reaction time is ok
AND     job quality      ! asks if the job quality is ok
AND     weather today  ! asks if the weather today is ok
AND     weather forecast   ! checks the weather forecast
AND     delay           ! asks if the current operation is
!                       delaying any other vital operation
AND     personal               ! asks about personal matters

OBJECT  job             ! asks what job you are performing
AND     fuel type    ! asks what fuel type you are using
!               -----------------------
!       The following statements will initialize the max
!       speeds. Plowing max is initialized to zero
!       because the system loops through in 0.1mph steps
!       to find the horsepower limited speed for plowing
!       This is done because, in this system, it is not
!       easy to perform the mathmatics to solve a third
!       order equation.
!               -----------------------
INIT    plowing max := 0.0
INIT    cultivating max := 4
INIT    hoeing max := 11
INIT    discing max := 6
INIT    planting max := 6
INIT    drilling max := 6
!               -----------------------
!       This command sets the minimum threshold of
!       confidence. If the confidence level is less than
!       this, the fact is considered to be FALSE.
!               -----------------------
THRESHOLD = 50
!               -----------------------
!       This command suppresses the conclusions
!       reporting of the system. We will use our own
!       DISPLAYS to show conclusions.
!               -----------------------
SUPPRESS ALL
!               -----------------------
!       The following statements tell the system to
!       prompt the user for confidence factors for the
!       appropriate variables.
!               -----------------------
CONFIDENCE weather today
AND     weather forecast
AND     delay
```

```
AND     personal
AND     job quality
!               ------------------------
!       The following goal is defined so the system
!       strives to make it true, backward chains.
!               ------------------------
1. The final speed has been determined
!               ------------------------
!       The following rule is used to drive the system
!       to the final goal. The THEN elements of this
!       rule is the GOAL as described above. The
!       IF portions are the conditions that must be
!       found TRUE before the GOAL can be declared TRUE.
!               ------------------------
RULE    to do the evaluation of speed
IF      The speed may be evaluated
AND     PTOpower, job, and width are set
AND     depth is set
AND     Horsepower limited speed has been found
AND     fifteen mph speed limit is checked
AND     reaction speed has been checked
AND     draft required has been found
AND     crop value, fuel type & price, labor cost, and:
        area set
AND     initial hpratio is found
AND     initial fuel consumption has been found
AND     initial costs have been found
AND     labor considerations have been weighed
AND     quality of work has been checked and set
AND     hpratio has been found to check the slope of:
        the cost curve
AND     fuel consumption has been found to check slope:
        of cost curve
AND     cost has been evaluated to check the slope of:
        the cost curve
AND     slope of the cost curve has been checked and is:
        negitive
THEN    The final speed has been determined
AND     DISPLAY final speed
AND     FORGET draft required has been found
AND     FORGET initial hpratio is found
AND     FORGET initial fuel consumption has been found
AND     FORGET initial costs have been found
AND     FORGET quality of work has been checked and set
AND     FORGET hpratio has been found to check the slope:
               of the cost curve
AND     FORGET fuel consumption has been found to check:
               slope of cost curve
AND     FORGET cost has been evaluated to check the slope:
               of the cost curve
AND     FORGET slope of the cost curve has been checked:
```

```
                and is negitive
AND     FORGET The final speed has been determined
AND     CYCLE
!               ------------------------
!       The following rule makes sure the operator is
!       ready to start the system, before allowing
!       him/her to continue.
!               ------------------------
RULE    to see if operator is ready to start
IF      DISPLAY start
THEN    The speed may be evaluated
ELSE    CYCLE
!               ------------------------
!       The following two rules asks the pertinent
!       questions for further evaluation.
!               ------------------------
RULE    to ask ptopower, job, and implement width
IF      ASK ptopower
AND     ASK job
AND     ASK implement width
THEN    PTOpower, job, and width are set

RULE    to find depth
IF      job IS plowing
OR      job IS cultivating
AND     ASK depth
THEN    depth is set
ELSE    depth is set
AND     depth := 2
!               ------------------------
!       The following six rules evaluate what the maximum
!       speed you can go with the tractor you have
!       indicated you are operating.
!               ------------------------
RULE    for plowing max speed as limited by horsepower
IF      job IS plowing
AND     plowing max := plowing max + 0.1
AND     draft required := (7+(0.09*SQR(plowing max)))*:
        implement width*depth*12
AND     draft1 := (ptopower*0.70*1980000)/(5280*:
        plowing max)
AND     draft required > draft1
THEN    Horsepower limited speed has been found
AND     plowing max := plowing max - 0.1
AND     maximum operating speed := plowing max

RULE    for rotary hoeing max speed limited by horsepower
IF      job IS rotary hoeing
AND     maximum operating speed := -(30/2.4)+:
        SQRT(SQR(30/2.4)+(4*ptopower*0.55*1980000/:
        (implement width*5280)))
```

```
AND     hoeing max := maximum operating speed
THEN    Horsepower limited speed has been found

RULE    for cultivating max speed, limited by horsepower
IF      job IS cultivating
AND     maximum operating speed := (1980000*ptopower*0.60:
        /(5280*(30*depth*implement width)))
AND     cultivating max := maximum operating speed
THEN    Horsepower limited speed has been found

RULE    for planting max speed as limited by horsepower
IF      job IS planting
AND     ASK row space
AND     maximum operating speed := (1980000*ptopower*0.55:
        /(5280*(300*12*implement width/(row space))))
AND     planting max := maximum operating speed
THEN    Horsepower limited speed has been found

RULE    for drilling max speed as limited by horsepower
IF      job IS drilling
AND     ASK opener space
AND     maximum operating speed := (1980000*ptopower*0.55:
        /(5280*(80*12*implement width/(opener space))))
AND     drilling max := maximum operating speed
THEN    Horsepower limited speed has been found

RULE    for discing max speed as limited by horsepower
IF      job IS discing
AND     ASK weight
AND     maximum operating speed := (1980000*ptopower*0.60:
        /(5280*(1.5*weight)))
AND     discing max := maximum operating speed
THEN    Horsepower limited speed has been found
ELSE    CYCLE
!               -----------------------
!       This rule makes sure the horsepower limit of speed
!       is not greater than what the operator can react to
!               -----------------------
RULE    set top limit of speed at fifteen mph
IF      maximum operating speed > 15
AND     maximum operating speed := 15
THEN    fifteen mph speed limit is checked
ELSE    fifteen mph speed limit is checked

RULE    find out reaction limit of operator
IF      ASK react
AND     react
THEN    reaction speed has been cnecked
ELSE    ASK maximum operating speed
AND     reaction speed has been checked
!               -----------------------
```

```
!       The following six rules evaluate tne job being
!       performed and determine the draft required to do
!       the job, the field efficiency, and timeliness
!       coefficient (k).  Also, the speed is checked to
!       ensure the tillage operation is within acceptable
!       limits.  Refer to ASAE D230.3 for the data used in
!       these calculations.
!              ------------------------
RULE    for plowing draft and variable setup
IF      job IS plowing
AND     maximum operating speed <= plowing max
AND     maximum operating speed >= 4
AND     draft required := (7 +(0.09*maximum operating:
        speed*maximum operating speed))*implement width*:
        12*depth
AND     field efficiency := 0.70
AND     k := 0.0001
AND     tractive efficiency := 0.70
AND     power := ptopower*tractive efficiency
THEN    draft required has been found

RULE    for cultivating draft and variable setup
IF      job IS cultivating
AND     maximum operating speed <= cultivating max
AND     maximum operating speed >= 1.5
AND     draft required := 30*depth*implement width
AND     field efficiency := 0.80
AND     k := 0.011
AND     tractive efficiency := 0.60
AND     power := ptopower*tractive efficiency
THEN    draft required has been found

RULE    for planting draft and variable set up
IF      job IS planting
AND     maximum operating speed <= planting max
AND     maximum operating speed >= 3
AND     draft required := 300*12*implement width/:
        (row space)
AND     field efficiency := 0.70
AND     k := 0.01
AND     tractive efficiency := 0.55
AND     power := ptopower*tractive efficiency
THEN    draft required has been found

RULE    for drilling draft and variable setup
IF      job IS drilling
AND     maximum operating speed <= drilling max
AND     maximum operating speed >= 2.5
AND     draft required := 80*12*implement width/:
        (opener space)
AND     field efficiency := 0.75
```

```
AND     k := 0.008
AND     tractive efficiency := 0.55
AND     power := ptopower*tractive efficiency
THEN    draft required has been found

RULE    for rotary hoeing draft and variable setup
IF      job IS rotary hoeing
AND     maximum operating speed <= hoeing max
AND     maximum operating speed >= 5.6
AND     draft required := (30+(2.4*maximum operating:
        speed))*implement width
AND     field efficiency := 0.80
AND     k := 0.028
AND     tractive efficiency := 0.55
AND     power := ptopower*tractive efficiency
THEN    draft required has been found

RULE    for discing draft and variable setup
IF      job IS discing
AND     maximum operating speed <= discing max
AND     maximum operating speed >= 4
AND     ASK weight
AND     draft required := 1.5*weight
AND     field efficiency := 0.75
AND     k := 0.01
AND     tractive efficiency := 0.60
AND     power := ptopower*tractive efficiency
THEN    draft required has been found
ELSE    DISPLAY max speed
AND     ASK maximum operating speed
AND     CYCLE
!               ------------------------
!       The following rule asks about your costs in the
!       operation and the value of the crop.
!               ------------------------
RULE    to ask fuel price, crop value, labor cost, and:
        area of crop
IF      ASK fuel price
AND     ASK crop value
AND     ASK labor cost
AND     ASK area
AND     ASK fuel type
THEN    crop value, fuel type & price, labor cost, and:
        area set
!               ------------------------
!       The following rules evaluate the three costs of
!       concern; fuel, labor, and timeliness on a per
!       acre basis.
!               ------------------------
RULE    for initial horsepower evaluation
IF      hprequired := (draft required*:
```

```
        maximum operating speed*5280)/(1980000)
AND     hpratio := hprequired/power
THEN    initial hpratio is found

RULE    to calculate gal/(hp-hr) for diesel
IF      fuel type IS diesel
AND     fuel consumption := (0.52*hpratio)+0.77-(0.04*:
        SQRT((738*hpratio)+173))
THEN    initial fuel consumption has been found

RULE    to calculate gal/(hp-hr) for gasoline
IF      fuel type IS gasoline
AND     fuel consumption := (0.54*hpratio)+0.62-(0.04*:
        SQRT(697*hpratio))
THEN    initial fuel consumption has been found

RULE    for initial cost evaluation
IF      ac := implement width*maximum operating speed*:
        5280*field efficiency/43560
AND     fuel := fuel consumption*hprequired*fuel price/:
        (ac*tractive efficiency)
AND     labor := labor cost/ac
AND     time := k*area*crop value/(ac*24*2)
THEN    initial costs have been found
!               ------------------------
!       The following rule asks the user about labor
!       considerations and weighs the importance of
!       weather and other scheduling considerations.
!               ------------------------
RULE    to ask about the weather, personal matters, and:
        operation delay
IF      ASK weather today
AND     ASK weather forecast
AND     ASK delay
AND     ASK personal
AND     ktime := 1 + .002 * (100 - CONF(weather today)):
                   + .002 * (100 - CONF(weather forecast)):
                   + .002 * CONF(delay)
AND     klabor := 1 + .005 * CONF(personal)
THEN    labor considerations have been weighed
AND     labor one := labor*klabor
AND     time one := time*ktime
!               ------------------------
!       The following rule checks to make sure the
!       operator is doing the quality of work he/she
!       desires.
!               ------------------------
RULE    to check job quality and set speed accordingly
IF      ASK job quality
AND     CONF(job quality) > 60
THEN    quality of work has been checked and set
```

```
ELSE    max op speedone := maximum operating speed - :
                0.009*(100 - CONF(job quality))
AND     DISPLAY quality bad
AND     maximum operating speed := max op speedone
AND     FORGET draft required has been found
AND     FORGET initial hpratio is found
AND     FORGET initial fuel consumption has been found
AND     FORGET initial costs have been found
AND     CYCLE
!               -----------------------
!       The next rules finds the points on the plot of
!       total cost to determine the slope.  This slope
!       could only be positive if fuel cost is very
!       high.
!               -----------------------
RULE    to start final horsepower and cost evaluation to:
        check slope of cost
IF      total := fuel+(labor*klabor)+(time*ktime)
AND     maximum operating speed := maximum operating:
        speed - 0.1
AND     FORGET draft required has been found
AND     draft required has been found
AND     FORGET initial hpratio is found
AND     initial hpratio is found
THEN    hpratio has been found to check the slope of the:
        cost curve

RULE    find gal/(hp-hr)
IF      FORGET initial fuel consumption has been found
AND     initial fuel consumption has been found
THEN    fuel consumption has been found to check slope of:
        cost curve

RULE    to set final cost for slope check of total cost:
        curve
IF      FORGET initial costs have been found
AND     initial costs have been found
AND     total1 := fuel+(labor*klabor)+(time*ktime)
THEN    cost has been evaluated to check the slope of the:
        cost curve
!               -----------------------
!       This rule check to see if the total cost plot has
!       a negative slope.
!               -----------------------
RULE    to check for fuel cost weight in totol cost
IF      rise := total - total1
AND     rise >= 0.0
THEN    go on
AND     FORGET hpratio has been found to check the slope:
               of the cost curve
AND     FORGET fuel consumption has been found to check:
```

```
                 slope of cost curve
AND      FORGET cost has been evaluated to check the slope:
                 of the cost curve
AND      FORGET draft required has been found
AND      CYCLE
ELSE     slope of the cost curve has been checked and is:
         negitive
AND      maximum operating speed := maximum operating:
         speed + 0.1
!                -------------------------
!        The following are the text for the questions to be
!        asked.
!                -------------------------
TEXT     fuel type

         Please enter the type of fuel you are using;

TEXT     maximum operating speed

         Please enter the maximum speed (in miles per hour)
         at which you can perform the [job] operation,
         based on reaction times, safety and ride comfort.

         Be sure this speed is less than the maximum
         recomended by the system.

TEXT     job

         Please enter the job you are presently performing;
         If you are not performing any of these, please try
         to choose the one that would most closely require
         the same horsepower as the job you are performing.

TEXT     implement width

         Please enter the width of the implement you are
         pulling, in feet;


TEXT     row space

         Please enter the spacing between the rows of the
         planter, in inches;

TEXT     opener space

         Please enter the row spacing between the openers
         of the drill, in inches;

TEXT     weight
```

Please enter the approximate weight of the disc you are pulling, in pounds;

TEXT depth

Please enter the depth you are pulling the implement, in inches;

TEXT fuel price

Please enter the current fuel price, in $/gal;

TEXT crop value

Please enter the current value of the present (or future) crop that this operation affects, in $/ac;

TEXT labor cost

Please enter the cost of your labor, in $/hr;

TEXT area

Please enter the area of land (in acres) that you are going to cover while doing this operation, for the [crop value] $/ac crop entered above;

TEXT weather today

Do you have good weather for [job], today ?

enter your confidence:

SPACE BAR = change confidence by tens

LEFT ARROW KEY = decrease confidence by one and/or change direction of SPACE BAR change

RIGHT ARROW KEY = increase confidence by one and/or change direction of SPACE BAR change

100 = positivly good weather

0 = positivly not good weather

TEXT weather forecast

Are you expecting good weather for [job], in the future ?

enter your confidence:

100 = positivly a good weather forecast

0 = positivly not a good weather forecast

TEXT delay

While [job], are you seriously delaying any other vital operation(s) ?

enter your confidence:

100 = you are positivly delaying another operation.

0 = you positivly are not delaying any other operation.

TEXT personal

Are there any personal matters of greater priority than [job] ?

enter your confidence:

100 = there are positivly matters of higher priority than [job].

0 = there are positivly no other matters of higher priority than [job].

TEXT react

The system has determined that, while you are [job][depth (4,2)] inches deep with a [implement width (4,2)] ft wide implement, pulled by a [ptopower (5,2)] hp tractor, you can go [maximum operating speed (4,2)] mph.

Can you travel that fast, still react adequately, be comfortable, and safe ?

TEXT ptopower

Please enter the PTO horsepower of the tractor you are operating;

TEXT job quality

```
        At this speed ([maximum operating speed (4,2)]
        mph), are you performing the [job] operation with
        the quality you desire ?

        enter your confidence:

            100 = you are positivly performing the
                  [job] operation with acceptable quality.

              0 = you are positivly not performing the
                  [job] operation with acceptable quality.


!               ------------------------
!       The following are the displays for results or
!       problems.
!               ------------------------
DISPLAY  start
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:                                                Page 1 of 3  :
:                                                             :
:  IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;  :
:  :                                                      :  :
:  :         EXPERT SYSTEM TO DETERMINE THE               :  :
:  :                                                      :  :
:  :           PROPER SPEED OF TILLAGE                    :  :
:  :                                                      :  :
:  :         WRITTEN BY:  STANLEY C. BLACK                :  :
:  :                                                      :  :
:  HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<  :
:                                                             :
:                                                             :
:                                                             :
:  Press Function Key 1 to view additional pages.             :
:                                                             :
:  Press Function Key 2 CONT to continue execution.           :
:                                                             :
:                                                             :
:                                                             :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:  S.P.O.T.                                      Page 2 of 3  :
:                                                             :
: SPeed Of Tillage (S.P.O.T) is an expert system to help :
: a tractor operator determine if he/she is traveling the:
: proper speed for the specific tillage operation at     :
: hand.  This will be accomplished by asking the operator:
: several questions about the present situation and      :
: making conclusions based on those answers.  These      :
: conclusions will be aided by the use of machinery      :
```

```
: management techniques described in ASAE STANDARD      :
: D230.3.  These practices allow a calculation of a cost :
: per acre for fuel, labor, and timeliness.  With these  :
: three costs in hand for the present speed, a new speed :
: can be compared in terms of its cost per acre to       :
: determine if it is feasible.                           :
:                                                        :
:  Press Function Key 1 to view additional pages.        :
:                                                        :
:  Press Function Key 2 CONT to continue execution.      :
:                                                        :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:  S.P.O.T.                               Page 3 of 3   :
:                                                        :
:                                                        :
: The function keys are active when they are highlighted :
: at the bottom of the screen.  F5 EXPL will give an     :
: explination of a question. F3 STRT will start the      :
: session completely over, erasing all values previously :
: known.                                                 :
:                                                        :
: Press F2 CONT to continue.                             :
:                                                        :
:                                                        :
:                                                        :
:                                                        :
:                                                        :
:                                                        :
:                                                        :
:                                                        :
:                                                        :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<

DISPLAY max speed
        You are not operating in the proper range of
        speeds for the given tillage job.  The proper
        speed ranges are:

                plowing          4   to  [plowing max]

                cultivating      1.5 to  [cultivating max]

                planting         3   to  [planting max]

                drilling         2.5 to  [drilling max]

                rotary hoeing    5.6 to  [hoeing max]

                discing          4   to  [discing max]
```

```
        Press F2 CONT to continue.

DISPLAY final speed

        From the information you have provided, the
        system has determined that your fuel cost is
        [fuel (4,2)] $/ac, your labor cost is [labor one
        (4,2)] $/ac, and your timeliness cost is [time one
        (4,2)] $/ac.

        According to this information, the system has
        adjusted (or maintained) your speed to (at)
        [maximum operating speed (4,2)] mph.

        When you are ready to evaluate your speed again
        please press F2 CONT to continue.  It is assumed
        that you are using the same tractor, pulling the
        same implement, at the same depth, for the same
        crop, and your labor and fuel costs are unchanged.

        To begin completely over again please press
        F3 STRT.

DISPLAY quality bad

        You have indicated that the job quality is not
        adequate at [maximum operating speed (4,2)] mph.
        The system will slow you to [max op speedone
        (4,2)] mph and re-evaluate your situation.

        Press F2 CONT to continue.
!                 ------------------------
!       The following are the expanded explanations for
!       the user when using the system, so that he/she
!       might better understand the purpose of answering
!       such questions.
!                 ------------------------
EXPAND  fuel type

                  FUEL TYPE

        The type of fuel is needed to determine the fuel
        consumption at the current speed.

        Press F8 BACK to continue.

EXPAND  maximum operating speed

                  DESIRED SPEED OF TRAVEL
```

Since you are not able to react at the speed the program suggests, you need to enter a maximum speed at which you feel you can safely travel.

Press F8 BACK to continue.

EXPAND job

TILLAGE JOB TO PERFORM

This is the job or tillage operation that you are performing. This must be known to calculate the costs involved in tillage.

Press F8 BACK to continue.

EXPAND implement width

WIDTH OF THE IMPLEMENT

Simply enter the width of the implement in feet. This value is used to determine the draft required to pull the implement as well as other factors.

Press F8 BACK to continue.

EXPAND weight

WEIGHT OF THE DISC

The weight (in pounds) of the disc must be known or estimated to provide information necessary to calculate the fuel costs associated with this operation.

Press F8 BACK to continue.

EXPAND row space

ROW SPACING ON THE PLANTER

You need to enter the spacing, in inches, between the rows on the planter. This is used to calculate the draft required to pull the planter, as well as the fuel cost.

Press F8 BACK to continue.

EXPAND opener space

OPENER SPACING ON THE DRILL

You need to enter the spacing, in inches, between the openers on the drill. This is used to calculate the draft required to pull the drill, as well as the fuel cost.

Press F8 BACK to continue.

EXPAND depth

DEPTH OF IMPLEMENT

The depth of the implement (in inches) is used in some draft calculations, and has a bearing on the cost estimates of the operation.

Press F8 BACK to continue.

EXPAND fuel price

PRICE OF FUEL

The price of fuel (in $/gal) is used in the calculations of cost for fuel usage of the current operation at the current speed.

Press F8 BACK to continue.

EXPAND crop value

VALUE OF THE CROP

It is important that you estimate the value ($/acre) of the crop that you are performing this operation for. This will be used in the calculations of the timeliness of this operation.

Press F8 BACK to continue.

EXPAND labor cost

LABOR COST

The cost you associate with your time (in $/hr) whether it is actual wages or an estimation of your worth, is used in the cost calculations for the labor involved in doing the current job at the current speed.

Press F8 BACK to continue.

EXPAND area

AREA TO FARM (THIS CROP)

The area of land (in acres) on which you will perform this operation. This pertains to the value associated with the impending crop. The area will determine how many days it will take to finish this operation at the current speed.

Press F8 BACK to continue.

EXPAND weather today

WEATHER TODAY

The weather conditions today affect the speed you should go by dictating if fuel economy should be sacrificed to finish more quickly.

SPACE BAR = change confidence by tens

LEFT ARROW KEY = decrease confidence by one and/or change direction of SPACE BAR change

RIGHT ARROW KEY = increase confidence by one and/or change direction of SPACE BAR change

Press F8 BACK to continue.

EXPAND weather forecast

WEATHER FORECAST

The weather in the immediate future affect the speed you should go by dictating if fuel economy should be sacrificed to finish more quickly.

SPACE BAR = change confidence by tens

LEFT ARROW KEY = decrease confidence by one and/or change direction of SPACE BAR change

RIGHT ARROW KEY = increase confidence by one and/or change direction of SPACE BAR change

Press F8 BACK to continue.

EXPAND delay

DELAY OF A VITAL OPERATION

You should enter 100 here if the current operation is, in any way, causing a delay in any vital operation such as planting or harvesing.

SPACE BAR = change confidence by tens

LEFT ARROW KEY = decrease confidence by one and/or change direction of SPACE BAR change

RIGHT ARROW KEY = increase confidence by one and/or change direction of SPACE BAR change

Press F8 BACK to continue.

EXPAND personal

PERSONAL REASONS FOR DESIRED SPEED-UP

If there are any personal reasons why you need to get done as fast as you possibly can, you should answer 100. This will add weight to the timeliness factors in the total cost equation.

SPACE BAR = change confidence by tens

LEFT ARROW KEY = decrease confidence by one and/or change direction of SPACE BAR change

RIGHT ARROW KEY = increase confidence by one and/or change direction of SPACE BAR change

Press F8 BACK to continue.

EXPAND react

REACTION TIME OF OPERATOR

If you cannot react at the speed the system recommends any reason, even if it is only part of the time, you need to enter FALSE here and slow down.

```
        Press F8 BACK to continue.

EXPAND  ptopower

                   HORSEPOWER OF THE TRACTOR

        Please enter the available PTO horsepower of the
        tractor.  This is used in the calculations of
        maximum speed and fuel cost. If PTO equivialent
        power is not known, estimate from the following:

        PTO horsepower = Drawbar horsepower/(0.96*TE)

        Press F8 BACK to continue.

EXPAND  job quality

                   QUALITY OF THE TILLAGE OPERATION

        This question asks you to make a judgement
        concerning the quality of the job you are doing.
        You need to take into consideration the final soil
        condition you desire after this tillage operation.
        Also, if you are performing any special jobs such
        as surface smoothing, chemical incorporation,
        clod breaking, residue control, weed control, or
        moisture control you should evaluate how good the
        job is being done.

                   SPACE BAR = change confidence by tens

              LEFT ARROW KEY = decrease confidence by one
                               and/or change direction of
                               SPACE BAR change

             RIGHT ARROW KEY = increase confidence by one
                               and/or change direction of
                               SPACE BAR change

        Press F8 BACK to continue.
!              ------------------------
!       An END statement must be placed at the end of the
!       Knowledge Base to signify that this is all of the
!       Knowledge Base.
!              ------------------------
END
```

APPENDIX B
GLOSSARY OF TERMS

The following glossary is intended to give the reader more information about how terms are used in this paper and is no way comprehensive or definitive.

Algorithm - A systematic set of rules that, if followed exactly, will solve a particular type of problem.

Backward Chaining - A control strategy that is started by the goal and then attempts to find evidence to support or disprove that goal.

Biological Interface - The interface of the machinery and the soil and vegetation.

Confidence - A measure of the certainty one has in a fact or relationship.

Confidence Factor - A numerical measure given to a fact or relationship to weight one's confidence in the correctness of his answer.

Closed Loop Control - A control system for an operation or process in which feedback in a closed path or group of paths acts to maintain output at a desired level.

Continuously Variable Transmission (CVT) - A transmission in which an infinite number of input-output ratios are possible, between given ranges.

Driving Rule - The rule which forces the system to continue until execution is complete.

Evidence - True facts or relationships which support a particular goal or conclusion.

Execution - The running or using of a computer program.

Expert - A person displaying unique skills or knowledge in a particular area of study or interest.

EXPERT-EASE - A Expert System development system that is example driven.

Expert System - A computer program that can emulate the level of performance by a human expert in a specific task domain.

Expert System Shell/Environment - A system of routines that facilitate the quick development of Expert Systems.

Firing - The execution of rules or program statements.

Fixed Costs - Costs that are independent of the use of the equipment. These include such things as taxes, housing, and insurance.

Forward Chaining - A control strategy that begins with the available information and attempts to find a conclusion based on that information.

Gear Up-Throttle Down - A concept to achieve fuel savings in tractor operation by shifting up and throttling down to give the same power at a lower throttle setting.

Goal Driven System - (see Backward Chaining)

Heuristics - Methods or "rules of thumb" to reduce the area of search of a large system. Heuristics do not guarantee correct results.

IF-THEN-ELSE Reasoning - A type of rule that consists of a condition, action, and an alternative action.

Inference - The process of deriving new facts form known facts, observations, or assumptions.

Inference Engine - A part of an Expert System that contains the rules, control elements, and structure of the knowledge base to make sound conclusions based upon inputs, facts, assumptions, or observations.

INSIGHT2+ - A Expert System development system produced by Level Five Research.

Job Quality - The operators judgement of how well he is doing the desired job on the soil and its surroundings.

Knowledge Base - The part of an Expert System that contains heuristics, facts, rules, and querying elements.

Knowledge Engineer - An individual who acquires, accesses, and assembles knowledge into a knowledge system.

MICROPROLOG-APES - A PROLOG based system for the development of Expert Systems.

MYCIN - An Expert System developed for the diagnosis of men-ingitis and bacteremia infections.

Natural Language - A method for the exchange of information in an established form of communication such as English.

Numeric Fact - Any fact that has a numerical value.

Object-Attribute Pairs - A method of knowledge representation that involves a context and some parameter about that context.

Power Limited Speed - The speed at which a given horsepower tractor can travel with the selected implement and conditions.

Power Shift Transmission - A transmission that employes hydraulics to shift gears.

Production Rule Language (PRL) - The language that INSIGHT2+ uses to represent and implement the knowledge base.

Quality Speed - The speed at which the job quality desired is achieved.

Reaction Speed - The maximum speed at which a vehicle operator has adequate reaction time, is comfortable, and feels safe.

Rule Base - (see knowledge base)

Rule Based System - A computer program or system that represents the knowledge in the form of rules.

Runtime - The time of execution of the program.

Simplefacts - Any fact that can be represented by a TRUE or FALSE condition.

Simulation - The initiative representation of the functioning of a system by means of computer systems.

String Facts - Facts that are represented by a "string" of characters.

Task Domain - The specific area of knowledge that an Expert System is concerned with.

Timeliness - Ability to perform an activity at such a time that quality and quantity of product are optimized.

Variable Costs - Costs which are dependent upon the use of the machinery.

APPENDIX C
QUICK REFERENCE TO INSIGHT2+ STATEMENTS USED IN THE SPEED OF TILLAGE EXPERT SYSTEM

The following quick reference to **INSIGHT2+** contains only those directives used in the speed of tillage expert system and does not show the syntax of use. The syntax of the directives shown here can be seen in appendix A, the implementation of the speed of tillage system in INSIGHT2+ For more details of system capabilities refer to the manual provided with the INSIGHT2+ package.

AND - A conjunctive statement used in IF-THEN-ELSE rules.

ASK - A statement used to tell the system to ask the user a question.

CONFIDENCE (CONF) - A statement used to declare a fact as needing the user to enter his confidence about its truth. Also may be used in mathematical manipulations to represent the confidence entered by the user about a specified fact.

CYCLE - Used to force the system to refire nonforgotten preceding rules.

DISPLAY - Used to display information by the knowledge engineer. Usually used to display system conclusions or advice.

ELSE - The alternative actions if the condition of an IF-THEN-ELSE rule is false.

END - The last statement of the knowledge base to inform the compiler that it is finished.

FORGET - A statement used to tell the knowledge base to forget the value of a fact or condition. Useful in conjunction with the cycle statement and for recalculation of selected facts.

IF - The conditional part of an IF-THEN-ELSE rule.

INIT - Used to initialize a fact to a given value.

IS - Used to test if an attribute is associated with a given object.

NUMERIC - Used to assign a fact as having numerical values only.

OBJECT - Used to assign a fact as an object-attribute pair.

OR - Used as a disjunctive clause in an IF-THEN-ELSE rule.

RULE - Used to signify the beginning of a production rule.

SIMPLEFACT - Used to assign a fact as having only TRUE and FALSE values.

SQR - Used to take the square of the number or elements inside the parenthesis.

SQRT - Used to take the square root of the elements inside the following parenthesis.

SUPPRESS - Used to suppress the concluding displays that are provided in the INSIGHT2+ development system at runtime.

TEXT - Used to define text for questions to be asked of the system user.

THEN - Used to define the action to be taken if the condition of an IF-THEN-ELSE rule is true.

THRESHOLD - Used to define the level of confidence at which the distinction between true and false is made for facts that use confidence factors.

TITLE - Used to define the title of the expert system. Always the first line of the system.

INSIGHT2+ contains relational, numeric, assignment, and editorial operators for use by the knowledge engineer. They are;

Relational Operators:

- < less than
- > greater than
- <= less than or equal to
- >= greater than or equal to
- = equal to

Numeric Operators:

- ( ) parenthetical
- * multiplication
- / division
- + addition
- - subtraction

Assignment Operator:

- := assign the right hand value to the left hand variable

Editorial Operators:

! every thing after this on a line will be treated as comments

: used to continue a line to the next

The following is a list of the possible uses of the function keys while executing a knowledge base using INSIGHT2+. Only those functions available during the sample execution in appendix D are shown here. It is assumed that if the user needs explanation of other functions he has access to the INSIGHT2+ system and manuals. The following words will be highlighted at the bottom of the screen when they are available.

CONT - Resumes knowledge base execution.

EXIT - Gives opportunity to leave INSIGHT2+.

EXPL - Activates a display of explanatory information provided by the knowledge engineer.

HELP - Gives helpful information.

MENU - Returns you to the main menu.

PAGE - Advances to the next screen or "page" of information.

PRNT - Allows the user to send textual displays to a printer.

STRT - Starts the knowldege base currently in memory.

UNKN - Used to indicate that you cannot answer the question.

WHY? - Used to enter the Report System of INSIGHT2+.

APPENDIX D
LISTING OF EXAMPLE RUN OF THE SPEED OF TILLAGE EXPERT SYSTEM

This appendix is a listing of the screens viewed when running the speed of tillage expert system as described in chapter eight. In actual use, the system would highlight possible function key uses at the bottom of the screen. The meanings of the highlighted function keys are provided in appendix C. It is assumed that if the reader is using the INSIGHT2+ system he has access to the manuals which explain the use of the function keys.

SPeed Of Tillage S.P.O.T

```
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
[[[[[[[[1111111000000 S T A R T  U P 0000111111111[[[[[[[[[
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM

MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
11112222[[[[ Press F3 STRT to start the system [[[[22221111
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
```

```
                 SPeed Of Tillage S.P.O.T
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:                                                    Page 1 of 2  :
:                                                                 :
:  IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;  :
:  :                                                         :  :
:  :              EXPERT SYSTEM TO DETERMINE THE             :  :
:  :                                                         :  :
:  :                 PROPER SPEED OF TILLAGE                 :  :
:  :                                                         :  :
:  :              WRITTEN BY:  STANLEY C. BLACK              :  :
:  :                                                         :  :
:  HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<  :
:                                                                 :
:                                                                 :
:                                                                 :
:  Press Function Key 1 to view additional pages.                 :
:                                                                 :
:  Press Function Key 2 CONT to continue                          :
:                                                                 :
:                                                                 :
:                                                                 :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

```
                    SPeed Of Tillage S.P.O.T
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
:  S.P.O.T.                                         Page 2 of 2   :
:                                                                 :
:        SPeed Of Tillage (S.P.O.T) is an expert system to :
: help a tractor operator determine if he/she is traveling :
: the proper speed for the specific tillage operation at    :
: hand.  This will be accomplished by asking the operator   :
: several questions about the present situation and making :
: conclusions based on those answers.  These conclusions    :
: will be aided by the use of machinery management          :
: techniques described in ASAE STANDARD D230.3.  These      :
: practices allow a calculation of a cost per acre for      :
: fuel, labor, and timeliness.  With these three costs in   :
: hand for the present speed, a new speed can be compared   :
: in terms of its cost per acre to determine if it is       :
: feasible.                                                 :
:                                                           :
: The function keys are active when they are highlighted at:
: the bottom of the screen.  F5 EXPL will give an           :
: explination of a question. F3 STRT will start the session:
: completely over, erasing all values previously known.     :
:                                                           :
: Press F2 CONT to continue.                                :
:                                                           :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

SPeed Of Tillage S.P.O.T

Please enter the PTO horsepower of the tractor you are operating;

:250

SPeed Of Tillage S.P.O.T

Please enter the job you are presently performing ....
If you are not performing any of tnese, please try to cnoose tne one that would most closely require the same horsepower as the job you are performing.

---> plowing

cultivating

rotary hoeing

planting

discing

SPeed Of Tillage S.P.O.T

Please enter the width of the implement you are pulling, in feet;

:6

SPeed Of Tillage S.P.O.T

Please enter the depth you are pulling the implement, in inches;

:6

SPeed Of Tillage S.P.O.T

The system has determined that, while you are plowing 6.00 inches deep with a 6.00 ft wide implement, pulled by a 250.00 hp tractor, you can go 9.70 mph.

Can you travel that fast, still react adequately, be comfortable, and safe ?

TRUE <FALSE>

SPeed Of Tillage S.P.O.T

Please enter the maximum speed (in miles per hour) at which you can perform the plowing operation, based on reaction times, safety and ride comfort.

Be sure this speed is less than the maximum recomended by the system.

:9

SPeed Of Tillage S.P.O.T

Please enter the current fuel price, in $/gal;

:2

SPeed Of Tillage S.P.O.T

Please enter the current value of the present (or future) crop that this operation affects, in $/ac;

:10

SPeed Of Tillage S.P.O.T

Please enter the cost of your labor, in $/hr;

:0.1

SPeed Of Tillage S.P.O.T

Please enter the area of land (in acres) that you are going to cover while doing this operation, for the 10.00 $/ac crop entered above;

:100

SPeed Of Tillage S.P.O.T

Please enter the type of fuel you are using;

---> diesel

gasoline

```
                    SPeed Of Tillage S.P.O.T

Do you have good weather for plowing , today ?

enter your confidence:
                    SPACE BAR = change confidence by tens
               LEFT ARROW KEY = decrease confidence by one
                                and/or change direction of
                                SPACE BAR change
              RIGHT ARROW KEY = increase confidence by one
                                and/or change direction of
                                SPACE BAR change

               100 = positivly good weather

                 0 = positivly not good weather

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX100
```

SPeed Of Tillage S.P.O.T

Are you expecting good weather for plowing , in the future ?

enter your confidence:

100 = positivly a good weather forecast

0 = positivly not a good weather forecast

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX100

SPeed Of Tillage S.P.O.T

While plowing , are you seriously delaying any other vital operation(s)

enter your confidence:

100 = you are positivly delaying another operation.

0 = you positivly are not delaying any other operation.

0

SPeed Of Tillage S.P.O.T

Are there any personal matters of greater priority than plowing ?

enter your confidence:

100 = there are positivly matters of higner priority than plowing .

0 = there are positivly no other matters of higher priority tnan plowing .

0

SPeed Of Tillage S.P.O.T

At this speed (9.00 mph), are you performing
the plowing operation with the quality you desire ?

enter your confidence:

100 = you are positivly performing the
plowing operation with acceptable quality.

0 = you are positivly not performing the
plowing operation with acceptable quality.

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX70

SPeed Of Tillage S.P.O.T

From the information you have provided, the system has determined that your fuel cost is 6.99 $/ac, your labor cost is 0.02 $/ac, and your timeliness cost is 0.00 $/ac.

According to this information, the system has adjusted (or maintained) your speed to (at) 7.70 mph.

When you are ready to evaluate your speed again please press F2 CONT to continue. It is assumed that you are using the same tractor, pulling the same implement, at the same depth, for the same crop, and your labor and fuel costs are unchanged.

To begin completely over again please press F3 STRT.

APPENDIX E
SEMANTIC NETWORK FOR THE SPEED OF TILLAGE EXPERT SYSTEM

The following is the semantic network used to devlop the speed of tillage expert system.

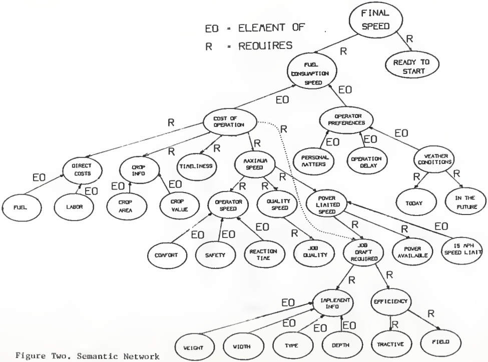

Figure Two. Semantic Network

UTILIZING EXPERT SYSTEMS
FOR
SPEED OF TILLAGE SELECTION

by

STANLEY CASH BLACK

8.S., KANSAS STATE UNIVERSITY, 1985

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

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Manhattan, Kansas

1986

ABSTRACT

Due to recent developments in both agricultural drive line optimization research and software availability for personal computers, the application of Expert Systems to speed selection for tillage operations has become an area of interest. Expert systems can be applied to this type of problem to aid a tractor operator in the selection of the most economical speed to pull tillage implements.

A joint study of the optimization of agricultural tractor drive lines was initiated in April, 1984, between the Agricultural Engineering and Mechanical Engineering Departments at Kansas State University. This project was aimed at developing computer controls to optimize an agricultural tractor drive line. After the mapping of the engine and transmissions, it was concluded that the development of an Expert Systems to determine the major input, desired speed of travel, would be the next logical step for a portion of the research team to investigate.

After several Expert System Shells were investigated, INSIGHT2+ was chosen to implement an expert system to determine the speed of tillage for a given operation and conditions. The knowledge that is included in the final system was then collected and entered into the INSIGHT2+

environment to produce an expert system.

The system was limited to six tillage operations; plowing, disking, cultivating, drilling, planting, and rotary hoeing. The information used to calculate performance for these operations was obtained from the ASAE Standards. This information included machinery management concepts to derive a total cost per acre for the operation at the current speed. This was then compared to costs at other speeds. The speed at which the operation cost the least, based upon fuel, labor, and timeliness costs per acre, was selected as the most economical speed to travel. The user is given an opportunity to reject the recommended speed based upon his comfort, safety, reaction ability, and the quality of job he is doing. These techniques proved to be adequate for this "proof of concept" system.

This expert system was tested by other engineers and was found to perform adequately. The system was interactive enough to allow the user to investigate most situations that occur during the performance of the given tillage operations. The one recommendation that has been made is that the system be made more flexible to allow a broader range of agricultural operations.

This project could lead to several other areas of investigation. First, the system has shown that it may possible to use expert systems to get a speed to input to a drive line optimization device to achieve both operator and machinery optimization. Secondly, a much broader system could be developed to include "all" agricultural operations for evaluations of problems such as combine troubleshooting.

This project has shown that it is possible to successfully apply expert system techniques to "real world" problems in Agricultural Engineering. Furthermore, it has opened many doors for further research as well as shown that such a system could be used with a drive line optimization device.