REDUCING THE MANUFACTURING AND MANAGEMENT COSTS OF TRACTORS AND AGRICULTURAL EQUIPMENT

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INTRODUCTION

Agricultural equipment improves productivity and reduces drudgery. But to be practical, such equipment must be affordable to the users and profitable for the manufacturers. Therefore, manufacturing productivity and efficiency of agricultural equipment is an important part of the systems engineering necessary to improve our food production systems.

In his plenar presentation to the Club of Bologna in 1989, Professor Renius introduced the "Project Foundation Matrix" (Figure 1) representation of the processes the agricultural industries use in the development of new products (Renius, 1989). This matrix provides a linkage between the new concepts for products that come from Product Planners or Advance Engineering groups and results in identification of a product development timeline including the influence of R&D, manufacturing, sales, service and finance. New concepts inputs to the process are heavily influenced by the state of the manufacturer in providing the capabilities to be found in new products. The output of the process is products that meet customer needs. This leads to consideration of product families (e.g, tractor series), re-use of well-developed subsystems (e.g., transmission and engine components), and manufacturing capabilities of the organizations. Strong supplier relationships have been used to provide those components that do not differentiate the manufacturer from their competition (e.g. hydraulic components). Over the years, these processes have interacted to result in a highly efficient organization for the production of agricultural equipment.

But the efficiencies that have been accomplished over the last twenty years are being further stressed to become more efficient in the face of decreased sales and changing distribution of the agricultural workforce worldwide. User requirements for additional electronics, controls and corresponding software further task the level of manufacturing efficiency while adding an ever increasing level of complexity to the management and manufacturing processes. To meet these additional requirements and because project management is an outgrowth of systems management, (Kerzner, 2001) traditional project management is migrating towards the use of system engineering tools. Through the application of these tools, the design, manufacture, and

J. Reid, J. Schueller, and W. Norris. "Reducing the Manufacturing and Management Costs of Tractors and Agricultural Equipment". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development". Vol. V. Invited Overview Paper. Presented at the Club of Bologna meeting November 16, 2003. Bologna, Italy.

life cycle of products are considered early in the project development cycle. Early application of the tools reduces cost, improves efficiency and minimizes risks associated with increased electrical content. This lecture will cover some of the manufacturing methods and the application of system engineering methods used in project management that can lead to decreased manufacturing costs of tractors and agricultural machinery.

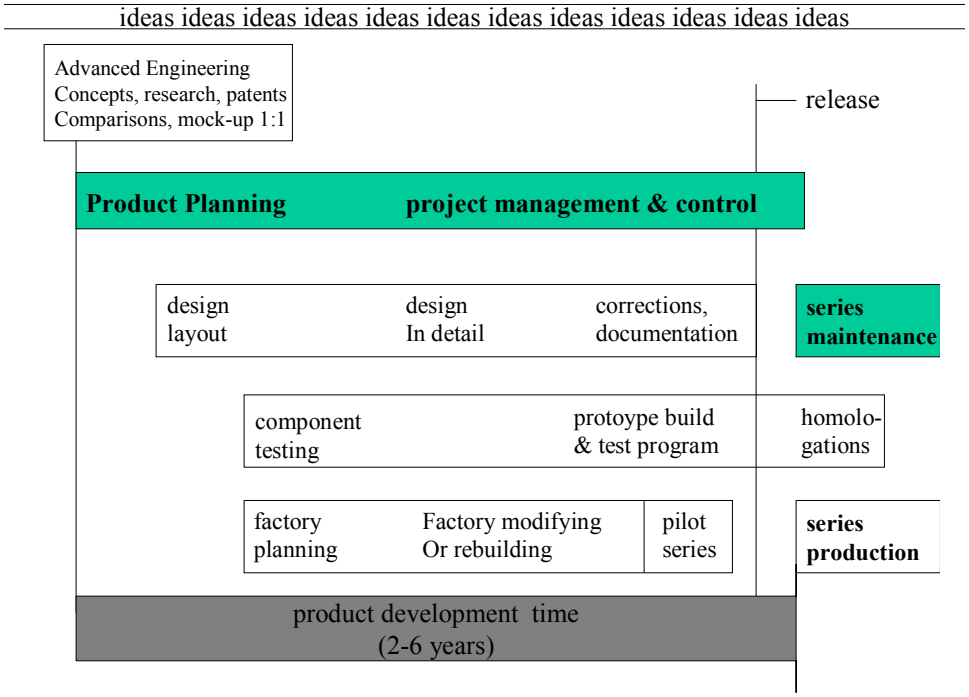

Figure 1. Example schedule of managing new projects (adapted from Renius, 1989)

Its manufacturing organization and manufacturing processes best characterize modern manufacturing in agricultural industries.

Manufacturing Organizations

There are a wide variety of agricultural manufacturing situations, usually even within individual countries. For discussion's sake, the situations can be crudely categorized as more-developed and less-developed, although it should be recognized that there is a continuum, rather than clear category demarcations.

The wide mechanization of agriculture in the more-developed countries during the 20th century has been widely recognized as one of the greatest engineering achievements and a key element in producing a high standard of living (e.g., Schueller, 2000). Industrial leaders, such as Henry Ford, built a mass production system for agricultural equipment which cheaply produced large quantities of reliable equipment.

But as those countries are now fully mechanized with large, productive equipment, the number

of units of agricultural equipment to be sold annually has decreased. Manufacturing organization in those countries has to shift to greater flexibility and the ability to be profitable at lower production numbers. Smaller inventories and changing requirements also require more rapid production. Such changes are not unique to the agricultural equipment industry, as they have occurred in other industries, such as aerospace.

The ongoing agricultural mechanization of some less-developed countries, such as India and China, is the most exciting area of the agricultural equipment industry. This can be approached in a variety of ways. Local technologies can be developed. Another alternative is to import whole goods. Sometimes designs may be imported and manufactured locally. Those manufacturing organizations utilizing mature, developed designs and production methods have the advantage of securing reliable, proven equipment.

But joint manufacturing should be considered as a possible alternative. Less-developed countries generally have available low-cost labor looking for meaningful employment. So they should perform labor-intensive activities, such as final assembly. They might also perform design and manufacturing activities related to local modifications to meet regional needs, as they are closest to those needs. On the other hand, it may be better to import components which utilize high technology or require higher manufacturing precisions from the more-developed countries. Examples of such components might include fuel injectors and electrohydraulic valves. Historically, there have been difficulties with communications and organization of such joint manufacturing. But with the advances in communications, such as the Internet and the increasing universality of the English language, such difficulties are easier overcome. It is important though not to discriminate against the less-developed countries. The design and manufacture of some high technologies in those countries may be appropriate.

Manufacturing Processes

The manufacturing processes represent a significant portion of agricultural equipment cost. Recent advances in these processes, some examples that are discussed below, can help reduce equipment cost.

Molds and dies are used for the rapid, cheap production of plastic and metal components. The traditional manufacturing of molds and dies follows distinct separate steps of machining, heat treatment, and finish grinding using different equipment and facilities for each step. This is time-consuming and expensive. More-developed countries have widely adopted the EDM (electrical discharge machining) process which is slow and sophisticated, but labor-efficient. Recent advances in cutting tool materials and milling machine structural dynamics and spindle speeds allow hardened steels to be cut directly into dies and molds. This technology has great potential for countries in most stages of development.

Rapid prototyping is a topic of much popularity in the more-developed countries. Direct manufacturing by those processes will likely only achieve a small penetration of the agricultural equipment industry in the more-developed countries for product development. But rapid tooling,

that is the use of rapid prototyping to build tooling, may become popular.

Plasma cutting and waterjet cutting are becoming standard processes in other industries. They are achieving widespread usage in the more-developed countries and will likely spread internationally.

High-speed machining (HSM) has become a vital part of aerospace manufacturing (e.g., Tlusty, 2000). Metal cutting gains can reduce manufacturing times to as little as 10-50% of conventional machining times through a thorough understanding of structural and process dynamics (Figure 2). Such productivity means that less machine tools are required to achieve the needed production.

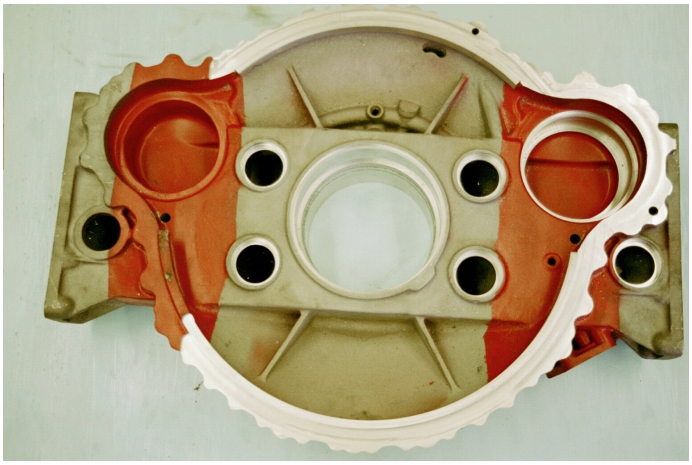

Figure 2. Aircraft casting machined in 15% of time of contemporary commercial practice using high-speed machining (Schueller, et al., 2004)

Composites are increasingly being used in equipment, including agricultural equipment. They produce light components and are feasible where the labor requirements of composites can be tolerated. There is also a potential to use local materials, such as glass fibers and biopolymers.

Design Issues for Manufacturing

Certain agricultural equipment design choices can reduce equipment manufacturing costs. This raises some areas in which good engineering and management can reduce manufacturing costs.

Several factors can influence the manufacturing costs. Standardization and reuseable components have proven historical value. Rising costs continue to be a problem within industry. One way to address these rising costs is through modularity. Modularity reduces costs to achieve product variety through modularity through combination and standardization. Electronics and the evolution of machines to mechatronic systems represents technological changes that can lead to a significant positive impact on increasing efficiency and reducing manufacturing costs. Other factors, like regulatory issues can result in significant costs for manufacturing if not anticipated.

Standardization

Standardization allows flexible utilization and reuse of components, economies of scale, and interoperability. Industry effort is strong in the standardization of mechanical systems. Technologies for electronics communications are also starting to make some progress. As with standardization of hitches, tires, belts, and power take-offs, the standardization of electronics and controls, such as networks and buses, will promote the advancement of agricultural equipment. But the rapid transition and impact of electronic functions require increased effort in this area. The industry is growing short of capable individuals to carry this activity forward.

Reusability of Components

Reusability of components and processes has become a central issue for design strategies. There are a number of reasons for this. The relative cost of development versus production is shifting more and more to greater investments in development. If you can go through one component design process and create a component design that can be used in a number of product variations or across product generations, or preferably both, you save tremendous amounts of money on development costs. You can also be very fast in bringing improved products based on selectively upgraded components to the market in the future. A second benefit of reusing components is that there are economies of learning and quality improvements at the component level. With time we learn how to make reused components cheaper and better. Reuse of components also increases product reliability. The more a component is reused and the more work is directed at incrementally improving that component and its production process, the higher the components reliability.

An example of the benefits of reuseable components would allow such items as custom tillage tools (e.g., Schueller, 1987) and machines and aids tailored to specific fruits and vegetables.

Modular Architecture

Modular design approaches used in development of mechanical, electrical, electronic, and software systems allow sharing of architectures/modules between different product lines. This modular design approach may provide economies of scale; reduced development time; reduced order lead-time; and easier product diagnostics, maintenance, and repair. Other benefits of this design approach include development of a variety of systems through component swapping and component sharing.

Backward and forward compatibility is always an issue in electronics and software because people have an installed base of equipment, programs, and files they don't want to sacrifice. Giving backward and forward compatibility to the consumer is a major benefit that a producer can choose to provide through a modular approach.

Business strategy also influences the impact of modularity. For some products, modularity can facilitate a proprietary architecture strategy in which only one company knows the critical interface specifications that make components plug-and-play compatible. Such a strategy would require fast upgradeability of a modular architecture to maintain an advantage in the market

place. Another alternative is to use modularity to maintain an open architecture strategy. This transfers many of the benefits of modularity to configure product variations and upgrades to the customers. In either scenario, it is important for the industry to recognize which aspects of a product differentiate the manufacturer and which are commodities. One example of this can be seen in GPS positioning technologies. In the short run, these systems might differentiate a manufacturer and provide benefits by maintaining proprietary architectures in the modular design. But eventually, accurate positioning might become a commodity that does not differentiate a manufacturer thus requiring compatibility within the industry.

Another example of the significant impact of a modular design strategy would be in the resale of agricultural equipment. The mechanical lifetime of a piece of equipment is much longer than that of the electronics due to the rate of technological advancements in software and electronics technology. Through the use of modular techniques, the electronics on a traded in piece of equipment could be easily upgraded, extending the equipment's effective lifespan and improving the attractiveness of the used equipment.

Electronics and Mechatronics Systems

Replacing mechanical functionality with electronic functionality might also reduce manufacturing costs. Just as electromechanical servomotors are computer-tuned to get responses based upon their industrial application, agricultural equipment components can be similarly adjusted. For example, the same electrohydraulic valves might give different optimal performances in different applications. Recent research has supported this concept (Qiu et al, 2000) where fuzzy control methods provided a common modular steering controller that could be used equally well on different tractor and combines.

Initially, the customer can interpret electronic content as a decrease in quality. One reason is the difference in life between mechanical and electrical components. Another reason is the serviceability. The average producer is typically familiar with the repair and maintenance of mechanical systems. The equivalent capability in electrical systems will take some time to evolve. A similar trend happened in the automotive industry in the 1980's. But today the modularity in design and component reliability, along with evolution of the service organization has resulted in customer acceptance. Agriculture will likely follow a similar trend.

In the markets of less-developed countries, it may make sense to have a slower adoption of electronic content in equipment since a critical issue is the serviceability of machines in the field. This is based on the presumption that less developed countries have an easier ability to support a mechanical-service infrastructure than an electrical-service based infrastructure. However, some developing economies will skip the traditional industrialization steps and will migrate to systems more like those used in developed countries. This is best facilitated in systems with large-scale organization of agriculture and the strong internal infrastructure to support agricultural manufacturing and production.

For agricultural equipment, there remains the issue of the life of the equipment. Modularity in

design against a rigid set of product requirements can anticipate the needs for modernization and serviceability over the product life cycle for many of the electronics and control systems.

Mechatronics is the synergistic combination of mechanical engineering, electronic engineering, control engineering, and information sciences (Figure 3). Mechatronics characterizes a general trend of increasing automation. Previous products have treated the mechanical and electronic design as separate entities. Fusion of these systems in design will lead to decreased costs in design and manufacturing and increased functionality. In effect mechatronics becomes the implementation of systems engineering principles to result in the efficient design of electro-mechanical systems.

Regulatory Issues

Governments in more-developed countries regulate safety, emissions, and fuel economy issues. Unfortunately, unlike power, traction, etc., the costs of the technologies to solve these issues are generally not scaleable with equipment size and thereby become too expensive for the equipment in the less-developed countries. Affordable, even if not optimal, solutions are needed to these issues.

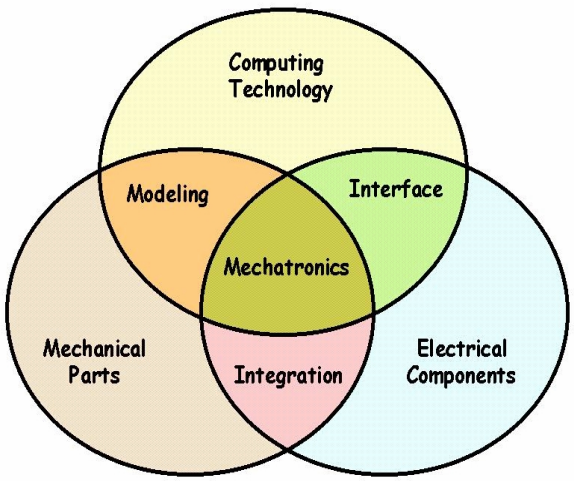

Figure 3. Mechatronics systems combine mechanical, electrical and computing technologies to create equivalent functionality (Zhang, 2003).

The current issue of emissions requirements to meet North American and European guidelines are creating pressures on the manufacturing of engines and power units in agricultural industries. Meeting these regulations can create difficulty in manufacturing by making certain models of equipment unprofitable. Keeping the industry healthy and profitable requires constant tracking of regulatory issues and estimation of their impact well in advance of their occurrence. This plays into the important role that university research and research organizations can play in identifying factors that will eventually impact manufacturing costs.

Safety issues have always been important for agricultural equipment. The infrastructure of manufacturers pay special attention to ensuring product meets expected regulatory guidelines for safety. But safety will be especially critical for the integration of newer technologies into the products for the consumer. Value-added features like automatic guidance can lead to increased productivity for the producer by increasing efficiency. But variations in the interpretation of guidance systems within governments will create problems if they require the implementation of safeguarding systems that are not universally affordable or supportable. And manufacturers will be entering the phase of taking responsibility for the closed-loop performance of the machine system, which has previously managed as the operator's responsibility. Decisions to increase productivity for the producer will have to be weighed against the safety requirements for products.

Optimization of Assembly, Design, and Service

Developed industries are continuously challenged by ways to become more efficient. The maturity of design and manufacturing processes allows an increased focus on making the overall system more efficient. This has lead to design methodologies to reduce the costs of assembly, design and service.

Design for Assembly is a methodology for evaluating product designs in a quantifiable way to identify unnecessary parts in an assembly and to determine assembly times and costs. The assembly time standards are based on extensive research confirmed by years of industrial usage. They cover wire harness and printed circuit board assembly as well as mechanical assembly. Product engineers assess the cost contribution of each part and then simplify the product concept through part reduction strategies. These strategies involve incorporating as many features into one part as is economically feasible. The outcome of a DFA-based design is a more elegant product with fewer parts that is both functionally efficient and easy to assemble. The larger benefits of a DFA-based design are reduced part costs, improved quality and reliability, and shorter development cycles.

Design for Manufacturing (DFM) methods provides guidance in the selection of materials and processes and generates piece part and tooling cost estimates at any stage of product design. DFM provides manufacturing knowledge into the cost reduction analysis of Design for Assembly. The method isolates the major cost drivers associated with a wide range of processes for part manufacture including finishing.

Unlike existing parametric cost estimating models, DFM does not rely on historical data and therefore allows you to quickly generate accurate cost estimates as the parts are being designed. Alternative materials and processes can then be quickly investigated. Quantitative cost information allows product development teams to base design decisions on real-time information to shorten product development time and build consensus among the team.

Design for Service (DFS) assists manufacturers in meeting the demand for ease of serviceability.

Serviceability, in particular, has become a key selling point for manufacturers of all types of goods. DFS methods allows designers and engineers to evaluate the serviceability of a product when it is in the early design stage, where changes can be made to the product design at minimal cost. The benefits of conducting a DFS analysis include reduced warranty costs, improved customer satisfaction, and more environmentally sensitive products due to longer life through economical servicing.

Systems Approach to Manufacturing

Systems engineering, initially developed and applied to the aerospace and software industries has since migrated to several other industries where products have become extremely complex. Due to current agricultural equipment complexity, some agricultural manufacturers are adopting systems engineering methods to reduce the costs of machinery and mitigate the risks involved in the design and manufacture of ever more complex machinery. A brief review of these methods and their utility will be provided. The basic goal of Systems Engineering is to provide an approach to enable the realization of high quality solutions through the effective integration of organized sets of components (Pirbhai et al, 2000). User needs and required functionality are defined and understood early in the development cycle. The approach then proceeds with design synthesis and system validation while considering the complete problem and product life cycle including disposal. In short, a systems approach considers both the business and the technical needs of all stakeholders with the goal of providing a quality product that meets the user needs. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

The systems approach has three major components in Figure 4 below:

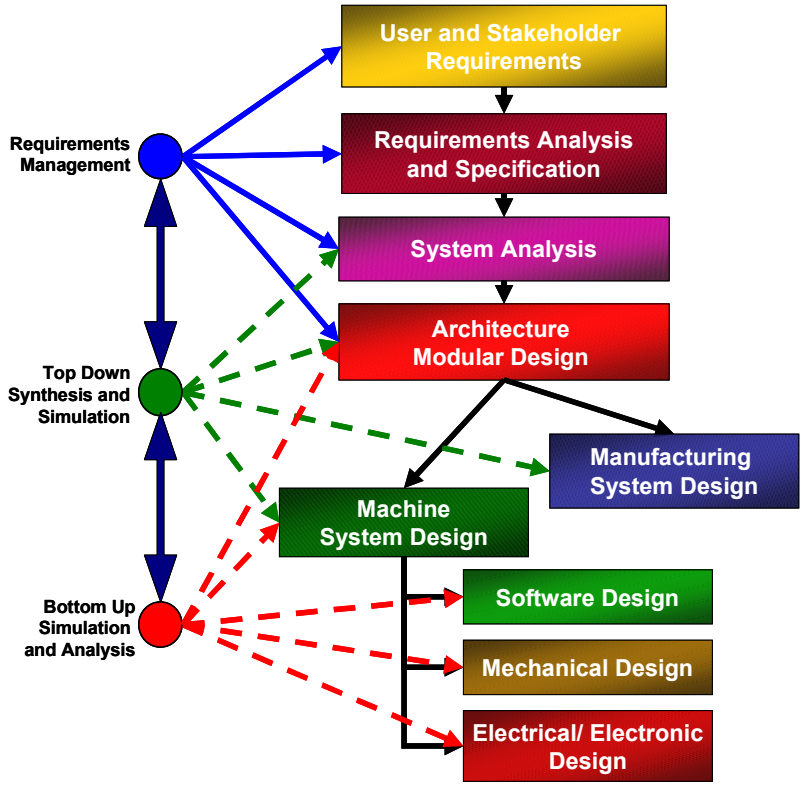

Figure 4. Systems approach to manufacturing

"Requirements Management" consists of requirements capture and allocation. Requirements capture involves capturing and using stakeholder requirements to yield product specifications while requirements allocation involves developing systems architecture possibilities and systematic requirements traceability. The modular components of a system or sub-system are defined by form, fit, function and input/ output definitions. Traceability is the ability to trace specifications back to the initial requirements to ensure that the design meets the requirements and that the product is not designed to include more than what is required. Traceability of requirements over the entire product lifecycle enables the product development team members to perform impact analysis. E.g., the project leader can inspect if the requirements in the functional requirements specification cover the requirements written in a commercial requirements document. The system architect can inspect the effect of changing a specific resource constraint. Requirements management and associated specifications set the structure and the interface definitions for a modular system architecture.

"Top Down Design and Simulation" and "Bottom Up Design and Simulation" used in the design process will improve product quality while eliminating prototypes, reduce product delivery cycle time, and optimize machine performance. "Bottom Up Simulation and Analysis" which involves simulation and analysis starting from the component level and working upward. Examples would include the finite element analysis of wheels and three-dimensional dynamic simulation of

a tractor. Rapid prototyping, virtual simulation, and design for assembly and manufacture are possible methods that may be involved. "Top Down Synthesis and Simulation" involves product development (synthesis) from upper level requirements. For example, fleet system simulation and optimization, synthesis of machine systems, to synthesis of kinematics. An additional aspect of this process is the design of modular system architectures as previously discussed.

Virtual prototyping is a method of decreasing the amount of time between the design phase and the time of introduction of a new product into the marketplace, allowing simultaneously for improved quality. A virtual environment (VE) allows engineers to interact with their designs (i.e., a vehicle model) in three dimensions in real time. These simulation models require an adequate understanding of the agricultural system and the components that work in it. Although agriculture has made significant strides in this area, there is a lot to know about systems that would be useful in design.

The concept of virtual prototyping may be extended, with a future objective being an integration of design and simulation in a distributed virtual environment, including equipment design, system analysis, manufacturing design, FEA analysis, verification and validation of the complete system. Design, verification, and validation will include hardware, software, electronics, control systems and software. In this structure, many elements of the product design may be performed concurrently.

- With a human operator in the simulation loop, hidden user requirements will be captured and used to adapt control system parameters in x-by-wire systems so that they reflect operator preferences and filter environmental influences on a particular task to be controlled (human augmentation). (Norris, 2001).
- Intelligent, mechatronic and control systems may be trained and developed in the same manner, using rapid prototyping hardware-in-the-loop technologies to train and compile the onboard software configurations and control system parameters. (Norris et al, 2003)

Industry is actively involved in developing and pursuing developments in virtual simulation techniques and virtual environments. Virtual training environments have been developed for complex equipment, where operators can operate a machine and learn the controls in a safe and controlled environment.

Summary and Conclusions

By proper consideration of manufacturing organization, contemporary advances in manufacturing processes, and related design issues, manufacturing costs can be reduced for agricultural equipment. This makes the equipment more affordable to the users and leaves a profit for the manufacturer. Consideration of the product life cycle early in the design process mitigates manufacturing risk, extends the life and value of the product. Systems engineering tools applied to the project management of design and manufacturing process will ensure manufacturing issues are addressed during the design process and that the final product meets the end-user requirements without over or under extending product capabilities. The use of virtual simulation and analysis will significantly reduce the need for prototype builds, reduce the time to

market and reduce software, power and electronic issues in the equipment early in the design cycle. The overall result of the application of these methods will be improvements in overall product quality with a significant reduction in both design and manufacturing costs.

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