SOCIOTECHNICAL SYSTEMS ANALYSIS AND DESIGN FOR SELECTING AND DESIGNING THE OPTIMUM MANUFACTURING PROCESS

by

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ABSTRACT

Given the requirement for a new manufacturing capability, there is a need to establish and implement the appropriate steps to ensure the development of a configuration that reflects the proper balance among *technical*, *social*, and *environmental* factors. Past experience has indicated that the *technical* characteristics of manufacturing plants, in general, have been emphasized, with little consideration given to *social* issues. This approach has been costly in terms of productivity losses, the price per product output has increased and, at the same time, outside competition has increased significantly.

The objective of this project is to select a manufacturing process that produces aluminum cans for a large market, identify some problems that have evolved as a result of the above approach, and to emphasize the importance of considering *social* issues in the development of a manufacturing capability. Sociotechnical systems analysis methods have been introduced throughout.

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INTRODUCTION

The Problem

Given the requirement for a new manufacturing capability, there is a need to balance technical, social, and environmental factors. The problem is *"How do you select and design a preferred manufacturing process which balances technical, social, and environmental factors?"* For example, if the manufacturing capability is a technical-centered design, designers will typically focus on incorporating new technology with some form of hardware or software to achieve some desired transformation or outcome. Without considering the social issues by "failing to actively involve employees throughout the change planning and implementation process invariably leads to a lack of commitment and, often, to overt or passive-aggressive resistance [6]." 85% of technical-centered designed projects fail (Reengineering Reviewed, 1994). Another example of a purely technical-centered approach is when the focus is on assigning to the machine any functions or tasks which its technology can enable to accomplish. Then, what ever is "left over" is allocated to the persons who must operate, maintain, or be serviced by the system [6].

If the manufacturing capability is a social-centered design, the manufacturing process's performance criteria (productivity, product specifications, the need, etc.) may not be achieved due to the fact the technical issues were not considered.

The deficiency is not considering and balancing the social and technical factors (with respect to the environment characteristics) during the selection and design phases of the project.

The Need

In describing the problem, the appropriate steps related to the selection and design of the preferred manufacturing process focuses on balancing technical, social, and environmental factors. The technical considerations pertain to the manufacturing process that is being changed. The social considerations pertain to the engineers who design the manufacturing process and the plant personnel who have to support and maintain the manufacturing process.

The manufacturing process used to illustrate the need to attend to the social subsystem is a metal forming process in an aluminum can making system. Empty aluminum cans are being manufactured with production speeds in excess of 2,000 cans per minute. This particular can manufacturer (consisting of 18 production plants) produces over 20 billion cans a year. These cans are then sold to beverage filling companies, like Coke and Pepsi, and beer filling companies, like Anheuser-Bush and Miller. The metal forming process reduces the diameter of the top of the empty can. This reduction in the diameter of the top end of the can equates to metal being saved and millions of dollars saved each year.

The design engineers are focused on implementing new technology in the manufacturing process in meeting the organization's needs. The plant personnel are focused on maintaining and supporting the manufacturing process in order to meet the production needs of the organization. Currently, these two groups do not necessarily have to interface with each other. Historically new technology that was implemented into the company by the design engineers resulted in an organizational design which was not in alignment with the social characteristics of the workforce. New technology was normally a complex and rigid design which was very sensitive to productivity and social disruption. Instead of improving productivity, low production, absenteeism and poor operator well being became common.

The market in the can industry is very competitive due to price wars and limited customers compared to can making suppliers. This means that some organizations have high metal costs figured into their total costs. This is due to the current processes that use too much metal in producing the can. Therefore, with a very competitive and saturated can industry, the organization's internal costs become very critical in determining a profit or loss for the organization.

As previously stated, the focus of this project and report is on selecting and designing a metal forming process with the objective of using less metal in the manufacturing process. This reduction in metal usage will equate to reducing the manufacturing process's total costs. This means a can company can then pass the cost savings onto the customer and consumers and get more orders. The can company can then produce more cans and take business away from it's competitors. This establishes the need to reduce costs in the manufacturing process.

The current metal forming process uses 0.012" (inches) thick of aluminum sheet metal to make a can. By using less metal in the metal forming process, moving from 0.012" (inches) to 0.010" equates to a 0.002" reduction in metal usage. For every 0.002" reduction in metal usage, the company saves $0.50 per 1000 cans being manufactured. This means if a can company makes 20 billion cans a year, a $10 million dollar per year savings can be realized for the company. If this cost savings is passed onto the customer/consumer who buys 400 million cans a year from the can manufacturer, it would save $200 thousand dollars for that year. This cost savings for the customer (like Coke or Pepsi) can then sell their products at a less expensive rate to the consumer, who would buy more because the buying price was less. The cause and effect would be more orders for the can manufacturer and more production from the can plants.

The Approach

The aim of this project and report is to illustrate how Sociotechnical Systems (STS) Analysis can provide a process for selecting and designing the optimum manufacturing process by balancing technical, social, and environmental factors. If a manufacturing process is selected and designed solely from a technological viewpoint and does not consider the social work system's viewpoint of maintaining and supporting the technology or the environment that the manufacturing process must operate within, the outcome will be an optimized technical subsystem and a suboptimized total system. A selection and design process must exist in order to keep people from making the critical mistake of optimizing the technical subsystem (or optimizing the social subsystem) and suboptimizing the total system. The Sociotechnical Systems Analysis process is essential to providing the solution to this problem.

Sociotechnical Systems Analysis seeks to broaden each person's knowledge of social and economic consequences; to treat the work system as the unit of analysis; to jointly optimize the social and technical subsystems; and to maintain self regulation and redundancy of skills in work systems. Sociotechnical Systems Analysis regards systems as open, acquiring and adopting change through people [1].

The Systems Engineering Process (SEP) will be used to describe the overall system of the new manufacturing process in terms of a can plant, input/output unit of analysis. Once the input/output model has been developed, another figure will be presented to illustrate the hierarchy of the systems involved within the can plant. The system operational requirements will be developed to determine the new system's performance and effectiveness characteristics. Then the system maintenance concepts will be developed to identify the maintenance levels and the basic functions that need to be performed at each level (i.e. organization, intermediate, depot and/or supplier). Once the new system operational requirements and maintenance concepts have been developed a system functional analysis will be used to illustrate the operational and maintenance functional flow diagrams. The functional flow diagrams will then delve down to the design options that the Sociotechnical Systems Analysis will evaluate in terms of selecting and designing the optimum manufacturing process.

Description of The System

The manufacturing process exists in a can plant and is illustrated by figure 1 with an input/output can plant diagram.

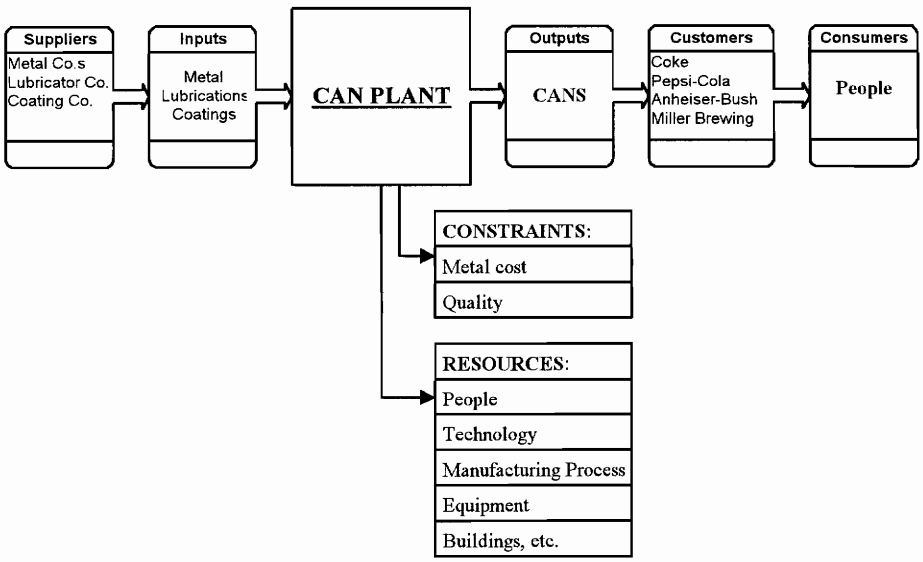

Figure 1. Can plant - input/output system.

The hierarchy of the systems within the can plant is illustrated in figure 2. Figure 2 shows the can plant at the top of the system, the metal forming system at the next lower subsystem, and finally the new metal forming process with the next lower subsystem.

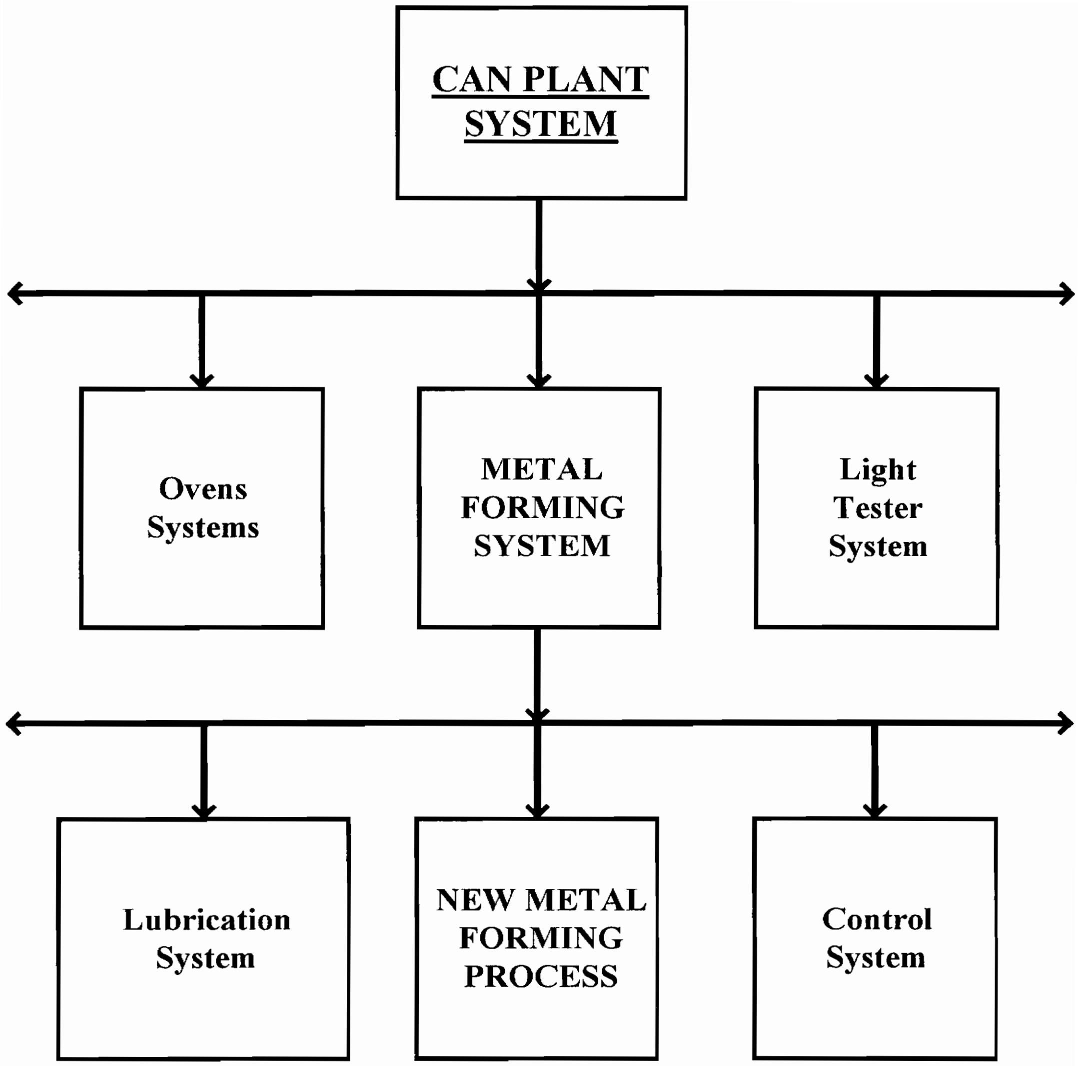

Figure 2. Hierarchy of systems - can plant.

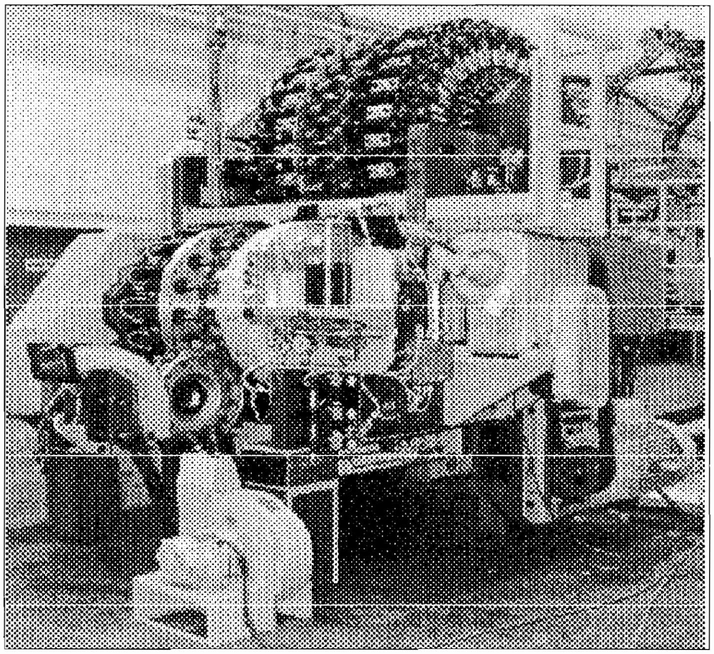

Figure 3. Metal forming system.

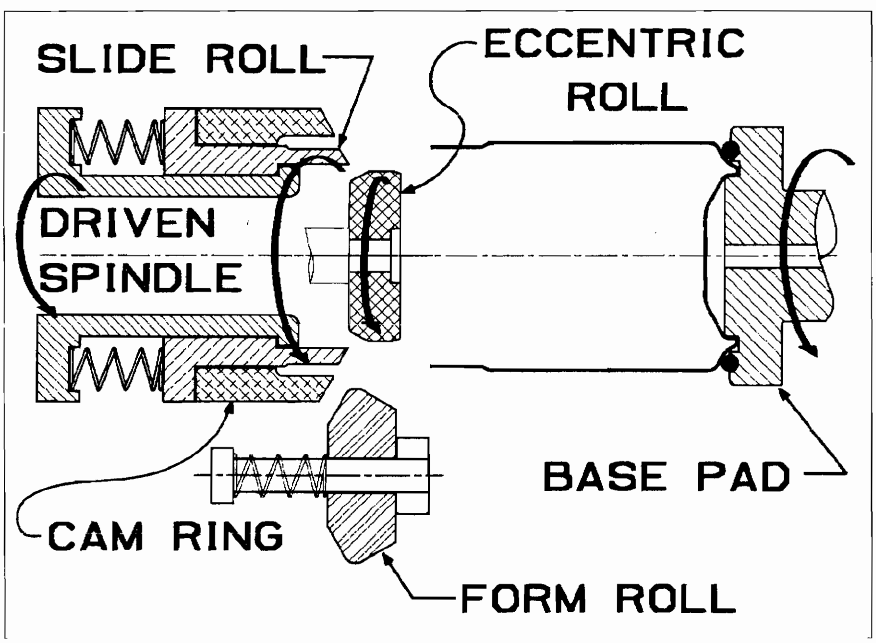

Figure 4. Metal forming process.

Figure 3 illustrates the metal forming system and figure 4 illustrates the metal forming process. Both of these subsystems exists within the can plant system.

THE SYSTEMS ENGINEERING PROCESS

Stated below are the system operational requirements that describes the system performance and (effectiveness) characteristics of the new manufacturing system. The system operational requirements represent the basic mission to be accomplished (i.e. overall function that the new manufacturing system is to perform).

System Operational Requirements

A.) Mission definition:

- The system must be able to produce a 2.02 inch can opening from a 2.11 inch wide by 4.13 inch high aluminum can with flangewidth (can open lip) measurements of 0.070 inches, +/- 0.005 inches and plug diameter (inside diameter of the top of the can) to be 2.050 inches, +/- 0.005 inches. These product measures will be checked once a shift (every 8 hours). This is what the new metal forming design is suppose to accomplish.

B.) <u>Description of the design/operating parameters:</u>

- The system must not exceed 12 feet in height, 10 feet in width, and 20 feet in length.
- The system cannot weigh over 50 tons.
- The system must be able to produce 2.02 inch open end aluminum cans at a rate of 2,400 cans per minute.
- The efficiency of the system must operate at least at a 99.955% rating. Meaning there will be no more than 0.045% spoilage produced or 1 can damage from the operation of the machine at 2,400 cans per minute for 12 hours of operating time.
- The system must be able to operate using power rated at 480 volts, line to line, 3 phase, 60 hertz.
- The system must be variable speed controlled to follow the varying production line speed.
- The system shall produce cans to meet the specified fifty (50) pounds of column load strength (strength of the can).
- The system shall produce cans to meet the specified zero (0) metal exposure rating (testing of cans for leakage).

C.) Use requirements

- The system must be able to operate 24 hours a day, 350 days in a year. The minimum rated speed shall be at 2,400 cans per minute.
- The system must operate at rated speed and efficiency within the first hour after a 24 hour maintenance shutdown.

D.) Operational life cycle (horizon)

- The system shall operate a minimum of ten (10) years at rated operated speed and efficiency.
- The system shall produce 1.26E9 cans per year for ten (10) years.
- The system shall be operated by plant personnel (i.e. (3) shifts of plant personnel, each shift of eight (8) hours long) who have attained a minimum of a high school diploma and are familiar with can machinery operating in an industrial environment.

E.) Effectiveness factors

- The mean time between maintenance (MTBM) shall not exceed a frequency of more than once (1) a month.

- The failure rate (lambda) shall not exceed a frequency of more than once (1) every five (5) years.
- The maintenance downtime (MDT) shall not exceed twenty-four (24) hours per frequency.
- The system shall not consume no more than eleven (11) cents per hour of power usage in order to be energy cost effective.
- The system shall not produce no more than one (1) bad can per minute of rated operational speed of 2,400 cans per minute in order to be cost effective.
- The system shall be available and dependable to operate for twenty-four (24) hours a day for 350 days in a year.

F.) Operating industrial environment

- The system must operate in temperatures from fifty (50) up to one-hundred and thirty (130) degrees Fahrenheit.
- The system must operate in a dirty industrial type of environment requiring a NEMA-12 rating of electrical enclosures.
- The system must operate at sea level, zero (0) mile, up to one (1) mile high level.
- The system must operate twenty-four (24) hours a day for 350 days in a year.

- The system shall be capable of being transported by ground or air. Storage in warehouses can be used if necessary.
- The system shall be capable of being handled by industrial rigors to load and off-load the system as necessary.

System Maintenance Concepts

The system maintenance concepts identify the maintenance levels and basic functions to be performed at each level (i.e. organization, intermediate, depot, and/or supplier) of the new system.

A.) Organizational maintenance.

- The new system must be able to have on-site maintenance, on the machine in the production line. This level of maintenance will be performed by plant technicians involving minor service, removal and replacement of some components, external adjustments, visual inspection, and operational checkout of the machine.
- The plant, the consumer, will provide parts, purchased from the producer's spare parts lists, and tools to perform the necessary work to bring the system back into production mode as soon as possible.

- The plant will be solely responsible for this level of maintenance.
- Testing equipment and test philosophy will be only limited to the interconnection of the machine upon installation. For example, testing will be done up to the point of the "black box" and not any further. The environment will be a noisy, dirty industrial production atmosphere.

B.) <u>Intermediate maintenance.</u>

- The plant will be responsible for the next higher level of maintenance above the organizational maintenance. This level will entail a more detailed inspection/system checkout, major servicing, major equipment repair and or modifications, complicated adjustments, and limited calibration being done.
- All of this work will be done off line from the production line in the plant's maintenance shop.
- The plant will carry a limited amount of parts purchased from the producer's spare parts lists.
- The plant's maintenance department personnel will perform tests to determine if the repairs or work can be done at the plant level or at the producer's level.
- The environment for this maintenance will be in an isolated part of the plant where it is not too noisy and dirty.

C.) Depot or producer maintenance.

- If the new system requires a major overhaul/rebuilt, complex equipment repair/modification, detailed calibration, detailed inspection/system checkout or if the intermediate maintenance level cannot handle all of it's work, this level will perform the necessary work.
- The producer who is responsible for all of this level of maintenance is the Company itself, located at it's central headquarters.
- Test equipment and testing philosophy will be at the highest level in the design work. The producer will have all parts available for it's use.
- The working environment will be very quiet and in a clean working area.

D. Social requirements (Personnel safety and well being)

- Personnel safety is a major priority. The major objective is to minimize (if not eliminate) the possibility of introducing human error in the performance of system operation functions and in the accomplishment of maintenance tasks [2].
- A safety analysis with the task and error analysis will be performed to determine the description of the hazard, cause of hazard, and identification of hazard effects.

- Operator well being will be measured in terms of stress tests, job satisfaction surveys, absenteeism, etc..
- Intrinsic motivational aspects of the job must be designed into the worksystem to enhance job commitment, job satisfaction, and the desire to take ownership of their worksystem for continuous improvement.

Functional Flow Diagrams

After the system operational requirements and maintenance concepts have been developed, the next phase is to do a functional analysis in identifying the major functions that the new system is to perform (based on the operational requirements and maintenance concepts), through functional flow block diagrams, in defining system design requirements in functional terms. The system functional analysis is a process of translating system operational and support requirements into specific qualitative and quantitative design requirements [2]. Figures 5, 6, and 7 represents the new metal forming process's operational and maintenance functional flow diagrams.

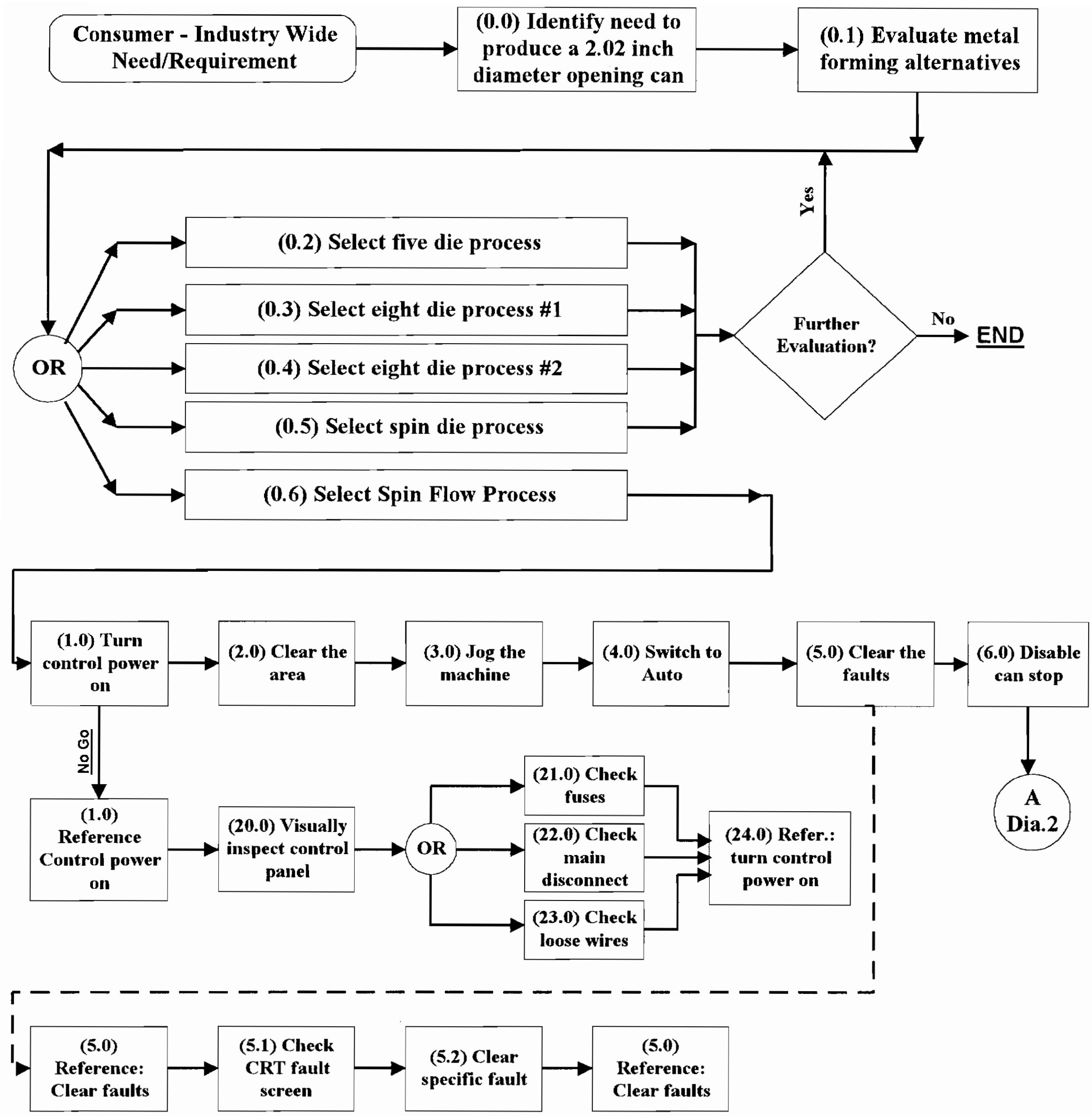

Figure 5. Operational/Maintenance functional flow diagram #1.

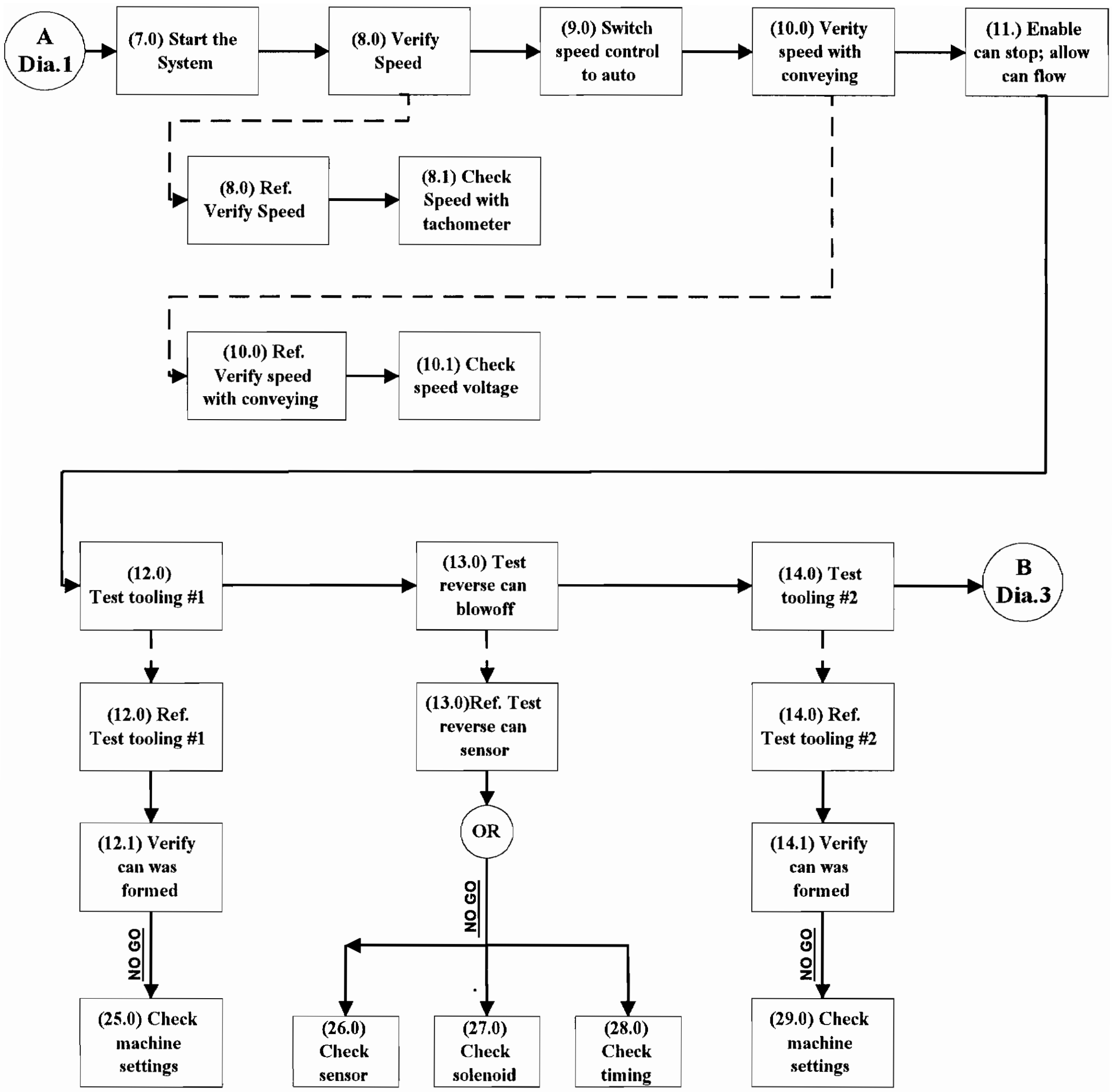

Figure 6. Operational/Maintenance functional flow diagram #2.

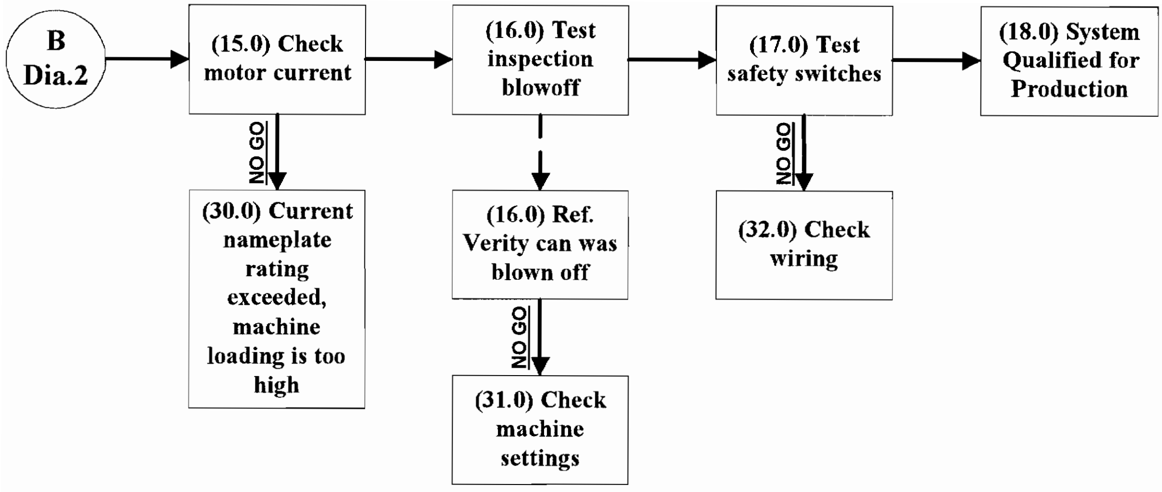

Figure 7. Operational/Maintenance functional flow diagram #3.

EVALUATION OF MANUFACTURING PROCESS ALTERNATIVES

The Systems Engineering Process, through the operational requirements, maintenance concepts, and functional flow diagrams, delved down to the problem level of, "How do you select and design the preferred manufacturing process?" As illustrated in figure 5 and again in a more focused view in figure 8 are the manufacturing process alternatives.

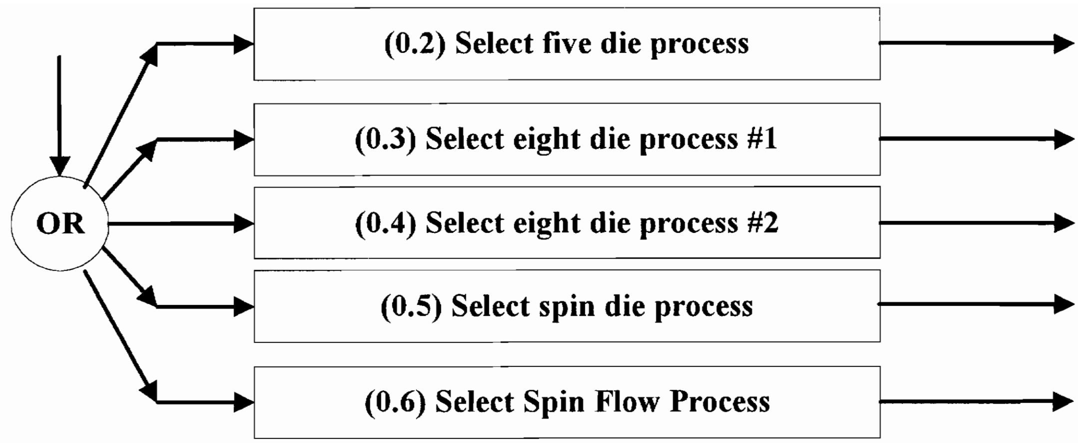

Figure 8. Alternative manufacturing processes.

The Sociotechnical Systems Analysis will provide a top-down assessment driven approach in identifying the key variables and design for the selection of the preferred, optimum manufacturing process.

SOCIOTECHNICAL SYSTEMS ANALYSIS APPROACH

The selection and design of a new process is typically performed by designers who do not consider “operator well being” as a performance measure and will focus on the technical subsystem and productivity alone. While the outcome of optimizing the technical subsystem may improve productivity (i.e. through automation), the system may fall short in terms of employee self-worth, stress, satisfaction, and related health and safety [6]. Optimizing the technical subsystem without considering the social subsystem may therefore suboptimize the total system. Reengineering does just this. Reengineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed [10].

On the other hand, optimizing the social subsystem without regard to the technical subsystem may also suboptimize the total system. Deengineering does just this. Deengineering involves redesigning organizations according to natural order and principles so they can be continuously responsive and adaptive [4].

How does one deengineer? Organizations are seen as complex living systems, networks of relationships that thrive on information and are capable of reorganizing themselves in response to dramatic changes in the environment. The notion is if people simply have access to one another and to information, they create the order they need to get the work done.

What is missing is a joint optimization approach, which balances the technical and social subsystems. The objective is achieving a fully harmonized work system at both the macroergonomic and microergonomic levels.

The macroergonomics level pertains to the third generation of ergonomics, the organization/machine interface. Macroergonomics is a top-down, assessment-driven approach to the identification of relevant variables and design of a harmonized sociotechnical system that prescribes a participative approach to microergonomics [1,5]. The microergonomics level pertains to the second generation of ergonomics, the user-friendly/system interface, and the first generation of ergonomics, the human/machine interface.

Joint optimization focuses on balancing the reengineering and deengineering perspectives through joint design, as illustrated in figure 9. Joint causation refers to the notion that the technical subsystem and the social subsystem are both affected by the environment, which means both subsystems respond to causes in the environment [1].

A harmonized system can be characterized by being synergistic, where the whole is more than the simple sum of its parts [6]. Synergistic can also be defined as a second-order relationship, which are those relationships that are complementary and add to system performance, with the first-order relationship as being functionally necessary to each other [2]. Applying STS, through the macroergonomic approach, and carrying this through to the microergonomic design of jobs and human/system interfaces, the resulting ergonomically *harmonized* work system should result in outcomes that are more than a simple sum of the parts would indicate [6].

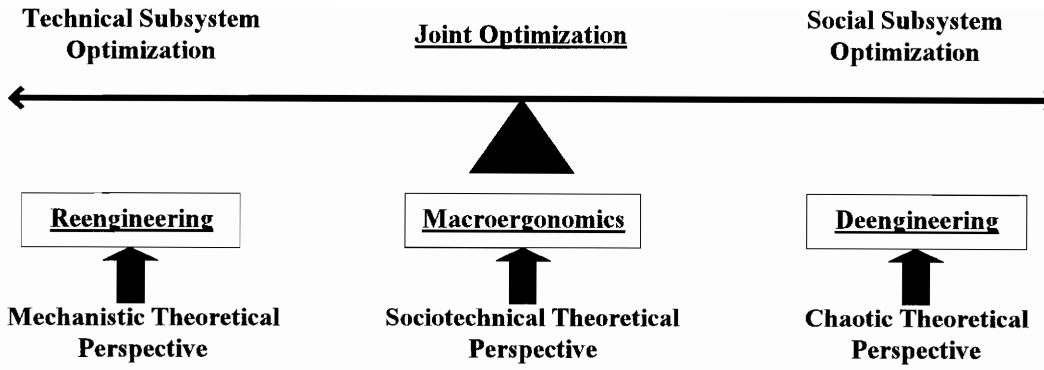

Figure 9. Sociotechnical Systems Theory/Joint Optimization Model.

Figure 9 illustrates the proposed conceptual relationships among macroergonomics, sociotechnical systems theory, deengineering, and chaos theory [1]. Using macroergonomics (sociotechnical theoretical perspective), in balancing the reengineering (mechanistic theoretical perspective), with the deengineering (chaotic theoretical perspective), will achieve a joint optimization of the technical subsystem and social subsystem. Joint optimization is accomplished through the joint design of the technical and social subsystems. The goal is to achieve joint optimization of having the technical and social subsystems optimized or balanced with respect to the environment, in which both subsystems (technical and social) interact with each other at each human/machine interface. Employee participation is the process by which joint design is achieved.

WHAT IS SOCIOTECHNICAL SYSTEMS ANALYSIS?

Sociotechnical Systems Analysis is characterized by three core principles: joint causation, joint optimization, and joint design. Joint causation refers to the notion that social and technical subsystems are both affected by the environment (i.e. both interact with each other at every human/machine interface, thus they are interdependent and operate under joint causation, meaning that both subsystems are affected by causal events in the environment). Since both subsystems respond to causes in the environment, optimizing one suboptimizes the other. Joint design is the method by which joint optimization is achieved. Joint optimization thus requires joint design of the technical and social subsystems, given the objectives and requirements of each, and the nature of the relative external environment [1,6].

Macroergonomics Level

Sociotechnical Systems (STS) Analysis, at the macroergonomic level or organization/machine level, is a top-down approach to system design that pertains to the joint causation of the four major components that interact and affect system functioning of the manufacturing process: (a) the technological subsystem, (b) the occupational roles and relationships, personnel or social subsystem, (c) the characteristics of the external environment that permeate the organization, or in this case the manufacturing process, and

(d) the organizational design dimensions. It is top-down in that it begins with an analysis of the relevant sociotechnical system variables in terms of their implications for the design of the overall structure of the work system and related processes. In short, it involves a systematic analysis of the key characteristics of the manufacturing process's technology, social subsystem, and external environment which permeates the manufacturing process and upon which it is dependent upon [6].

Once the key characteristics of the overall work system have been determined, they, in turn prescribe many of the characteristics that need to be microergonomically designed into the individual jobs, specific work processes, and related human/machine and user-friendly/system interfaces. The result is a fully harmonized/jointly optimized work system at both the macro- and microergonomic levels [6].

The macroergonomic level is the third generation of ergonomics. It is concerned with ergonomics research, development, and application of organization/machine interface technology. The goal of macroergonomics is a fully harmonized work system at both the macro- and micro-ergonomic levels [1, 6]. The key Sociotechnical Systems design principles are as follows:

(a) *Technology subsystem* - knowledge based - the design of the technical subsystem defines the tasks to be performed [5].

- *Task variability* or the number of exceptions encountered in one's work. Depending on the technology, these can range from routine tasks with few exceptions to highly variable tasks with many exceptions [5].
- *Task analyzability* pertains to the type of search procedure one has available for responding to task exceptions, or task analyzability. For a given technology, the search procedures can range from tasks being well-defined and solvable by using logical and analytical reasoning to being ill-defined with no readily available formal search procedures for dealing with task exceptions. Problem solving must be based on experience, judgment, and intuition [5].

The task variability and task analyzability can be analyzed further in detail by table 1.

Table 1.
Technology subsystem - task analysis.

TASK ANALYZABILITY	TASK VARIABILITY	
	Routine with Few Exceptions	High Variety with Many Exceptions
Well Defined and Analyzable	**Routine**	**Exceptions**
Ill Defined and Unanalyzable	**Craft**	**Nonroutine**

A brief description of each of the core components of the task analyzability and variability are as follows:

- *Routine* technologies [5] can be defined as having few exceptions; tasks are well defined; have high formalization; and is centralized.
- *Non-routine* technologies [5] can be defined as having many exceptions; tasks are difficult to analyze in terms of problems; are flexible; is decentralized; with low formalization.
- *Exceptions* or engineering technologies have many exceptions; are well defined in terms of rational and logical process; requires centralization; has flexibility; and low formalization.
- *Craft* technologies have routine tasks; rely heavily on experience, judgment, and intuition; problem solving requires particular expertise; requires centralization; and low formalization.

(b) *Personnel subsystem* or the *social subsystem* pertains to the degree of professionalism and psycho-social characteristics of the workforce [5]. Macroergonomics is human-centered in that the decisions regarding the structure of the work system require consideration of the worker's professional and psycho-social characteristics, and of the relevant characteristics of the external environment to which humans must effectively respond (in addition to consideration of the key characteristics of the technology to be employed). Consideration of these characteristics make it a humanized task approach to function and task allocation [6].

- *Degree of professionalism* refers to the skills and training requirements of the organization.
- *Psycho-social* factor or the cognitive complexity of the nature of the work involved with the people. This refers to the concreteness-abstractness of thinking or cognitive complexity as underlying different conceptual systems for perceiving reality.

(c) *Environment.* As stated in open system terms, organizations require monitoring and feedback mechanisms to follow and sense changes in their relevant task environments and the capacity to make responsive adjustments. All specific task environments vary along two dimensions that influence the effectiveness of an organization's design. These are the degree of [5]:

- *Change*, is the extent to which a given task environment are dynamic, or remains stable over time.
- *Complexity*, refers to whether the components of an organization's environment are few or many in number.

These two dimensions in combination determine the environmental uncertainty of the organization. There are two types of environment uncertainty classifications; *stable* and *simple* environments, and *unstable* and *complex* environments [5].

(d) *Organizational Design Dimensions of Macroergonomics*. The fourth major component of the Sociotechnical Systems Analysis is the organizational subsystem, which involves the consideration of the three STS components (technical, social, and environmental) that interact and affect system functioning [5,6]. The organizational dimensions are complexity, formalization, and centralization. These dimensions pertains to the structure of the organization and how it is managed.

- *Complexity* refers to the degree of differentiation and integration that exist within an organization. Three major kinds of differentiation exists within an organization. The three major kinds of differentiation that are inherent within an organization structure are: horizontal differentiation, vertical differentiation, and spatial differentiation [5].

    - *Horizontal differentiation* refers to the degree of departmentalization and job specialization that is defined into the organization.
    - *Vertical differentiation* refers to the number of hierarchical levels separating the chief executive position from the jobs directly involved with the system's output.

    - *Spatial differentiation* is defined as the degree to which a location of an organization's facilities and personnel are dispersed geographically from the main headquarters.

- *Formalization* is defined as the degree to which jobs within organizations are standardized [5].

- *Centralization* refers to the degree that formal decision-making is concentrated in an individual, unit or level (usually high in the organization) thus permitting employees (usually low in the organization) only minimal input into decisions affecting their jobs. *Decentralization* is preferred (a) when operating in a highly unstable or unpredictable environment, (b) when the design of a given manager's job will result in taxing or exceeding human information processing, and decision-making capacity, (c) when more detailed "grass roots" input to decisions are wanted, (d) for providing greater input to employees by allowing them to participate in decisions that affect their jobs, fully utilizing their mental capacities, and increase their sense of personal control and psychological significance to the organization, (e) for gaining greater employee commitment to, and support for decisions by involving them in the process, and (f) for providing greater training opportunities for lower-level managers [5].

Microergonomics Level

The Sociotechnical Systems Analysis at the microergonomics level pertains to the first and second generation of ergonomics. The first generation of ergonomics or human factors, as mentioned previously, pertains to the human/machine interface technology which related to the human factors being designed into processes that made the overall system safer, more efficient, and comfortable to work with. The second generation of ergonomics pertained to the way people think and process information and the cognitive nature of the work. This led to the user-friendly/system interface technology.
As Hendrick (1986) stated, "software structures, as well as knowledge about how people process and use information has made an impact on the user-friendliness or functional utility of computer-based systems."

SOCIOTECHNICAL SYSTEMS ANALYSIS (SELECTING AND DESIGNING THE OPTIMUM MANUFACTURING PROCESS)

This project and report will prescribe the process of selecting and designing a manufacturing process, using the Sociotechnical Systems Analysis approach. A validation plan will be prescribed later on in this project and report in order to justify this approach.

Sociotechnical Systems (STS) Analysis will entail an assessment phase and a preliminary joint design phase. The assessment and the preliminary joint design phases will select the preferred manufacturing design.

The Sociotechnical Systems Analysis and Design approach will complete the design of the preferred, optimum manufacturing process through the joint design & development phase, a production & construction - joint participation of function allocation phase, a measurement phase, and an evaluation phase.

Assessment Phase

As stated previously, macroergonomics takes a top-down, assessment-driven approach to the identification of relevant subsystem variables which will enable the design of a harmonized system.

The metal forming process (manufacturing process/design of the technical subsystem) and the social subsystem interact with each other at every human-machine interface. They are, thus, interdependent and operate under joint causation, meaning that both subsystems are affected by causal events in the environment.

This assessment phase of the STS process entails identifying the key variables of the technical, social and environmental subsystems, which are stated in table 2.

Table 2.
Key variables of the Sociotechnical Systems Analysis.

TECHNOLOGY SUBSYSTEM	**SOCIAL SUBSYSTEM**	**ENVIRONMENTAL SUBSYSTEM**
1.) Task Variability 2.) Task Analyzability	1.) Degree of Professionalism 2.) Psycho-social Factors	1.) Degree of Change 2.) Degree of Complexity

Systems theorists generally agree that complex systems are synergistic, that the whole is more than the sum of its parts. When applied to a manufacturing process, this suggests that using a macroergonomic approach, and carry this through to the microergonomic design of jobs and human/system interfaces, will result in ergonomically harmonized work systems that should result in outcomes that are more than a simple sum of the parts would indicate [6].

The objective of this assessment phase is employee involvement through participatory ergonomics. This process enhances human centeredness of the design process and takes advantage of the detailed knowledge of employees. This application of participatory ergonomics will lead to enhanced employee acceptance and commitment to the changes, and ultimately to the change of the corporate culture in positive ways that enhance safety and productivity [6].

Allocation of functions must be prescribed through out the analysis and design phases in order to assure the plant operators keep their mental models updated in what's happening with the manufacturing process they are managing. During this assessment phase the design team, consisting of engineers and human factors personnel, must prepare for design, clarifying requirements (based on the system operational requirements and maintenance concepts) and planning a design documentation base (again based on the stated system operational requirements and maintenance concepts). This documentation should identify functions, tasks and their components, and the *why* as well as the *what* for each decision [13].

In this assessment phase and based on the system operational requirements and maintenance concepts in strategically determining the organization design there should be low horizontal differentiation (low degree of departmentalization and job specialization based on the minimal amount of occupational specialists and minimal level of training required), high vertical differentiation (need to cut across all hierarchical levels in attaining the correct information based on the high number of levels separating the chief executive from the employees working directly on the system's output), and little integration (because of the low horizontal differentiation and high vertical differentiation). During the assessment phase there involves little span of control (number of subordinates that can be directly controlled by one supervisor), therefore the vertical differentiation would be good here.

Professionalism (based on the fact that the strategic decision makers are mature, experienced, and professionalized) is high in the assessment phase, therefore the formalization is low, as well as the centralization should be high (at this high level in the organization, formal strategic decision making is required).

The purpose of this phase is to use the assessment criteria described in table 2 in identifying the following variables regarding the options of figure 8: (1) task variability and task analyzability (technical subsystem); (2) degree of professionalism and psycho-social factors (social subsystem); and (3) degree of change and complexity (environmental subsystem). This identification process will determine the relationships that exists between the technical subsystem and the social subsystems and how they interact with the can plant environment. This is the assessment/identification process that takes place within each option of figure 8 in identifying the key subsystem variables that interrelate with each other.

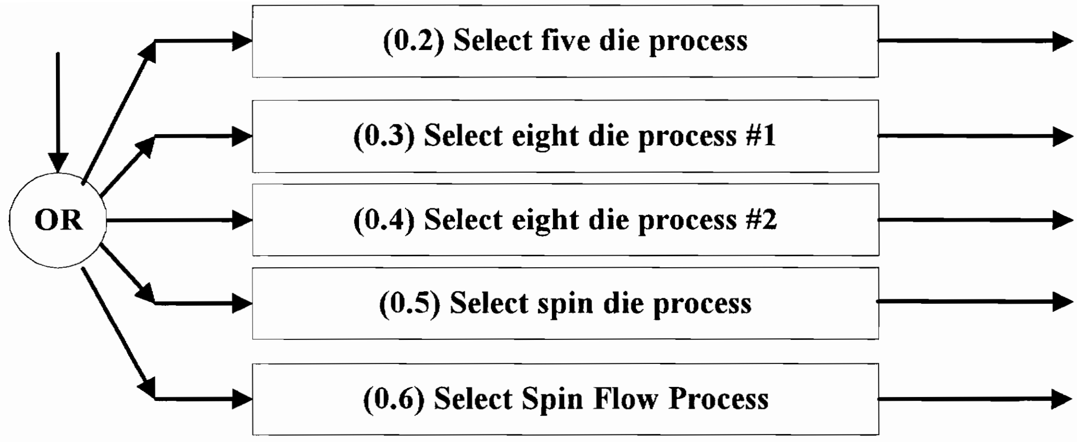

Figure 8. Alternative manufacturing processes.

This assessment phase identifies the key variables of the subsystems that will be further evaluated in the joint causation process of the next phase, the preliminary joint design and development phase.

Figure 10 illustrates the Sociotechnical Systems decision tree that will be used to select the preferred optimum manufacturing process, based on the potential capabilities of the five alternative manufacturing processes of figure 8.

The decision tree process begins with the Systems Engineering Process (SEP) evaluation. The SEP criteria must be satisfied or the manufacturing process being evaluated will be dropped from the selection process.

The next evaluation of figure 10 will entail an organization complexity analysis. The key here is to select the most potential manufacturing process that has the optimal organization design in mass producing aluminum cans and utilizing the features of the existing company's psycho-social work structure. This will be evaluated in terms of organization complexity. As mentioned before complexity refers to horizontal differentiation, vertical differentiation, and spatial differentiation. An increase in any one of these forms of differentiation will increase an organization's complexity. As the differentiation of an organization increases, the need for integrating devices, such as formal policies and procedures, also increases [12]. Increasing complexity has cause-and-effect relationships with decreasing formalization and decreasing centralization as well.

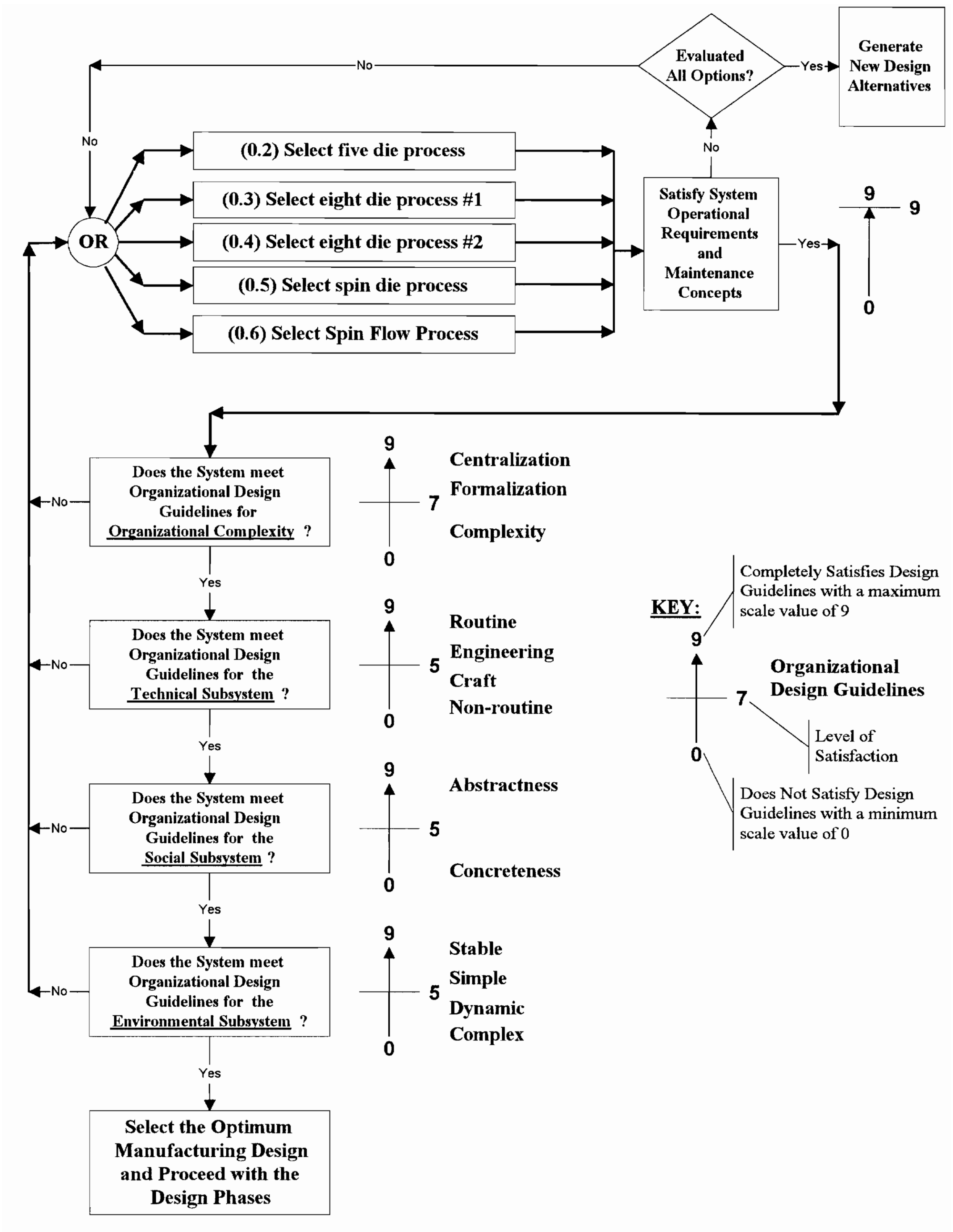

Figure 10. Sociotechnical Systems decision tree.

Justifying the STS decision tree of figure 10 begins with the System operational and maintenance requirements. The evaluation must be satisfied with a minimum scale level of 9 (the maximum). If this is not achieved the mission statement of the System operational and maintenance requirements will not be achieved and the need will not be satisfied.

The next evaluation entails the organizational *complexity* relationship with the other two core dimensions of the organization subsystem, *formalization* and *centralization*. This evaluation must be satisfied with a minimum scale level of 7. The goal is to have routine tasks designed into the manufacturing process. In order to achieve this, the manufacturing process must have low complexity. With low complexity, the manufacturing process can attain high levels of formalization and high levels of centralization. This optimum configuration will achieve routine tasks in supporting and maintaining the manufacturing process.

The next evaluation entails the technical subsystem relationships between the *routine*, *engineering*, *crafts*, and *non-routine* components. The objective is having well-defined tasks versus ill-defined tasks of the task analyzability process. This evaluation must be satisfied with a minimum scale level of 5, with a goal of achieving routine or engineering technologies, versus craft or non-routine technologies.

The next evaluation entails the Social subsystem relationships between *abstractness* and *concreteness*. The objective is having people operating the manufacturing process view reality (changes in the work system) with an open mind versus concreteness and a closed frame of mind. This evaluation will be satisfied with a minimum scale level of 5.

The last evaluation entails the Environment subsystem relationships between the *stable/simple* dimensions versus the *dynamic/complex* dimensions. The objective is having a manufacturing process being able to adapt to either the stable/simple dimensions or the dynamic/complex dimensions. The survival of a company is it's ability to adapt to it's environment, therefore this evaluation will be satisfied with a minimum scale level of 5.

Preliminary Joint Design and Development Phase

After the assessment phase of the STS has been completed, the next phase is to perform a Sociotechnical System preliminary joint design. This entails taking the key variables identified in the assessment phase of the STS and doing a detailed evaluation of those variables in developing a preliminary joint design.

1.) Technical Subsystem

The technical subsystem of the metal forming process can be analyzed in detail by table 1.

Table 1.
Technical subsystem - task analysis.

TASK ANALYZABILITY	TASK VARIABILITY	
	Routine with Few Exceptions	High Variety with Many Exceptions
Well Defined and Analyzable	**Routine**	**Exceptions**
Ill Defined and Unanalyzable	**Craft**	**Nonroutine**

- *Routine* technologies can be defined as having few exceptions; tasks are well defined; have high formalization (i.e. in terms of policies and procedures manual in how the manufacturing process is to be operated); and is centralized (i.e. in terms of formal decision making from the plant manager's level) [5].
- *Non-routine* technologies can be defined as having many exceptions; tasks are difficult to analyze in terms of problems; are flexible; is decentralized (i.e. in terms of decision making at the employee's level where the manufacturing process is being operated); with low formalization (i.e. in terms of having no written rules, procedures, or standards in how to operate the manufacturing process) [5].
- *Exceptions* or engineering technologies have many exceptions; are well defined in terms of rational and logical process; requires centralization (based on the same

explanation mentioned previously); has flexibility; and low formalization (based on the same explanation mentioned previously) [5].

- *Craft* technologies have routine tasks; rely heavily on experience, judgment, and intuition; problem solving requires particular expertise; requires centralization (based on the same explanation mentioned previously); and low formalization (based on the same explanation mentioned previously) [5].

2.) Personnel or Social Subsystem

The social subsystem's key variables that were determined in the assessment phase of the STS were the degree of professionalism and psycho-social factors.

The degree of professionalism relates to formalization in terms of training, education, values, norms, and expected behavior.

The psycho-social factors relate to the concreteness/abstractness of thinking or the cognitive complexity; the active exposure to reality versus a closed mindness, where there is no adaptation to change.

The selected manufacturing process must have met the following macroergonomic level criteria:

- System operational requirements and maintenance concepts in satisfying the needs performance and maintenance requirements stated previously in this project and report.
- *Task variability* in terms of routine tasks with few exceptions.
- *Task analyzability* in terms of tasks being well defined and analyzable.
- *Degree of professionalism* in terms of having the correct skills and training requirements in supporting and maintaining the selected manufacturing process.
- *Psycho-social factors* that determine the cognitive complexity of the nature of the work involved. This refers to the user-friendly/system/machine interface.
- *Degree of change* of the environment in that the new system must be able to adopt to dynamic and/or stable over time types of environmental changes.
- *Complexity* in terms of having the optimum amount of components designed into the manufacturing process, not too few and not too many.

Upon the completion of the assessment and preliminary joint design and development phases, the selection of the preferred manufacturing process would be made. The optimum manufacturing process that potentially fulfills the requirements of the criteria prescribed in the assessment and preliminary joint design and development phases is the manufacturing process to be selected.

For example, the capability analysis of the five alternative manufacturing processes can be analyzed with the decision tree of figure 10:

- Alternative "(0.2) Select the five die process" of figure 8, cannot meet the system operational requirements or maintenance concepts in terms of production speed (2,000 cans per minute) or product (2.02 can size) specifications. Therefore alternative (0.2) is dropped from the selection because the technology of the manufacturing process cannot meet the mission requirements of the process and product specifications.
- Alternative "(0.3) Select eight die process #1" potentially satisfies the system operational requirements and maintenance concepts of the level 1 analysis, but the design is so complex that the tasks to maintain and support this process are ill defined and unanalyzable. The plant personnel will never be able to take ownership of the process. This puts a burden on the social subsystem in having to have a high degree of professionalism among the plant people just to keep the process operating on a day to day basis. Therefore this process suboptimizes the social subsystem and it is dropped from the selection.
- Alternative "(0.4) Select the eight die process #2" potentially satisfies the system operational requirements and maintenance concepts; the task variability and task analyzability; but the design is not adaptable to change as easily as the other manufacturing processes. Therefore this process suboptimizes the environmental subsystem and it is dropped from the selection.

- Alternative "(0.5) Select the spin die process" potentially satisfies the task variability and task analyzability requirements, but the design does not meet the system operational requirements and maintenance concepts. The production and product capability specifications indicate a potentially high rate of process variation, which could lead to high product spoilage, high downtime, and high maintenance. Therefore this process suboptimizes the technical subsystem and it is dropped from the selection.
- Alternative "(0.6) Select the Spin Flow process" potentially satisfies: the system operational requirements and maintenance concepts; the organization complexity in terms of having the optimum balance of complexity, formalization, and centralization characteristics with the company's existing psycho-social work structure; the task variability and task analyzability requirements; the degree of professionalism and psycho-social requirements; and the degree of change and complexity requirements. This alternative manufacturing process potentially satisfies the evaluation criteria of figure 10, therefore the Spin Flow process has the best capability of becoming the optimum manufacturing process.

In the preliminary joint design and development phase, the allocation of functions process identifies functions, defining each *necessary* function in terms of it's inputs and outputs, and identifies a set of *accessory* functions [13]. For example, the necessary functions are those functions that are absolutely necessary for the manufacturing process to operate and achieve and satisfy it's mission requirements of the Systems operational and maintenance requirements. The necessary requirements are production speed (2,000 cans per minute), safety (personnel first, then equipment), etc.. The accessory functions add capabilities that are useful to the manufacturing process but are not critically required. The accessory requirements are spare parts, air conditioning, operator chairs, etc..

This completes the Sociotechnical Systems Analysis phase. The next step is to complete the design of the selected, potential, optimum manufacturing process. This will now entail the Sociotechnical Systems Analysis and Design approach, which will be explained from here on out of the project and report.

Joint Design and Development Phase

Once the assessment phase (identifying the technical, social, and environmental variables) and the preliminary joint design have been completed, the next phase is to participate in a technical and social joint design and development phase of the newly selected manufactured process.

Joint design of the metal forming process involves input and an active participation between the design engineers, plant supervisors and operators in the form of a cross-functional, self-managing team. The plant people bring a practical understanding in how existing production processes and the new metal forming process should be maintained and supported on a day by day basis, while the engineers bring a theoretical understanding in how the process should behave and react accordingly.

The *environmental* uncertainty level that the new metal forming process is to operate under has been determined to be stable and simple as well as dynamic and complex.

From the *technological* side, the task variability has been defined as being routine with few exceptions, and the task analyzability has been determined to be, well defined and analyzable. Therefore from the technological subsystem, the tasks will be classified as being routine.

From the *social* subsystem, or personnel side, the people involved with the design and implementation of the new metal forming system (a research and development project) should have considerable training and education (through formal education and acquired plant experience). Therefore the people involved with this phase of the process should have a high level of professionalism. At the same time, there should be some degree of formalization (standards in how you do your work), but be willing to adapt to the change because this is truly a research and design project, so therefore there should be a low level of formalization and centralization. For example, in a research and development project the company will use mature, experienced, and professionalized personnel. Therefore if the professionalism (skill levels) is high, you will have low formalization (i.e. in terms of written rules, procedures, and standards in doing their work) and low centralization (i.e. the decision making becomes decentralized in this level) [12].

Also from the *social* subsystem point of view, the people should have an abstract or cognitively complex frame of mind, meaning the people participating must have an active degree of exposure to diversity and is willing to change their perceptions and interpretations in how they conceptualize the world. They must be open minded, versus closed minded or having a concrete mindset [5]. Horizontal differentiation will be required in order to accommodate the specialization of the new metal forming process's technology, therefore departmentalization will be structured to implement the new technology. Since horizontal differentiation exists, some form of cross functional teams, or integration, will be required to keep the communication, control and coordination between the newly formed departments. Decentralization is required in this phase, all critical design decisions must be made within the design teams area of responsibilities.

At the microergonomic level of the STS process, the design team must humanize the work system by creating a healthy and safe quality of work life. The outcome will increase employee commitment and reduce related costs. This is the human/machine interface of ergonomics design phase relating to the first generation of ergonomics. This can be accomplished by getting participatory input from the plant personnel in how the new metal forming system should be ergonomically designed for operating the system, doing regular product quality checks, maintaining the system under "jam" conditions, performing regular maintenance procedures, and so forth. At the same time, the design engineers need to follow state-of-the-art national safety design guides, like the OSHA (Occupational Safety Health Association) and NEC (National Electrical Code) design standards. The design engineers need to address the plant personnel as their main audience, while the plant personnel need to acquire the theoretical knowledge (from the engineers) of the new metal forming process in order to understand, trouble-shoot, maintain, and support the new process.

Also the design team needs to implement procedures and methods (whether they are hardcopy manuals or computerized workstations) in helping the operators and other plant personnel understand the behavior of the new metal forming system so they can maintain and support the system under production conditions. This is the user-friendly/system interface (cognitive nature of the work) of ergonomics design or the second generation of ergonomics.

Using computerized tools (spreadsheets, predictive analysis software packages, artificial intelligence, neural networks, plant floor real-time animated production line screens, etc.) to generate forms and reports to portray information (in terms of trends and patterns) of the manufacturing process, will help the plant personnel and engineers to better understand the behavior of the new manufacturing process. This process illustrates another joint design and development phase on incorporating the cognitive nature of the work system of the user-friendly/system interface with the new manufacturing process.

You cannot maintain, support, or fix something, if you cannot understand the behavior of the system, and you cannot understand the behavior of the system if you cannot measure it.

The outcome of this phase is a balanced design consisting of a metal forming system that produces cans in excess of 2,000 cans per minute. The cans being produced from this system will be of high quality, meeting production and product specifications. The tasks that are required to support and maintain this system are routine and well defined and analyzable. This means the metal forming process is a safe system that should have low downtime and maximum operating time.

The operators, supervisors, and other plant people will have the appropriate levels of professionalism, education and training, to maintain, support and continuously improve the process. They will have an open-mind attitude so when the environment changes (e.g. process varies), they can adapt and correct/stabilize the process.

The monitoring and feedback system engineered into the system will give the operators, supervisors, and other plant personnel the right information, at the right time, and to the right person, in order for them to make the best decision and then to take the appropriate action in responding to their area of responsibility.

In the joint design and development phase, the allocation of functions process hypothesizes design solutions. This is the major step in the design cycle, the step at which interaction takes place between engineering, allocation and human factors decisions [13]. For example, the design engineers will hypothesize the interaction of plant personnel and the manufacturing process of each functions required to operate and maintain/support the manufacturing process (necessary and accessory functions). Then make an allocation hypothesis based on the design engineers hypothesis to determine what allocation of responsibilities are appropriate between humans and machines, giving special attention to control functions. Use a "men are better at - machines are better at" list to help form the allocation hypothesis, and then make a human factor hypothesis [13]. This process should be repeated until a mutually consistent set of hypotheses can be found for each function.

With the system engineered to accomplish the mission definition, stated previously in the System operational requirements, and satisfies the need, and the people macroergonomically (jointly designed) designed the system to be a safe, efficient and cost reducing process, the outcome should be realized as a balanced, jointly optimized, harmonized work system.

Production and Construction - Joint Participation of Function Allocations

The actual manufacturing, production and testing of the prime system and support elements occurs during this phase. Also, the allocation of functions process will test and evaluate the allocation hypothesis prescribed in the previous joint design and development phase. It is in this phase that the training and experience of the human factors personnel will be of significant value in locating and interpreting relevant data on human performance [13]. For example, downtime of the manufacturing process can be evaluated in how quickly the operator can bring the manufacturing process back into production and how complex the manufacturing process is in maintaining and supporting it. Another example would be the spoilage or bad product measures to determine if the operators can measure and identify process variation of the cans being produced to customer complaints due to receiving cans out of specification.

Hendrick (1995) stated that the primary methodology of macroergonomics is employee involvement via the method of participatory ergonomics. The objective is achieving employee acceptance and commitment to changes by enhancing the human centeredness of the design process and at the same time taking full advantage of the detailed knowledge of the design engineers who understand the theory of the process and how the metal forming system should behave, and the plant supervisors and operators who know how the metal forming system can be maintained, supported, and operated in a production environment. Therefore the design engineers will design (with joint participation of the plant personnel) the new metal forming system with the objective of having the plant personnel, take ownership of the process and to continuously improve the process. The plant personnel need to continuously give feedback to the design engineers, for valuable "grass roots" input.

The organizational design dimensions involved with this phase require low horizontal differentiation (because there are no special tasks required or departments to support these tasks) and low integration (since there is low horizontal differentiation). Vertical differentiation should be high because of the supportability and maintainability issues involved with day to day production. Formalization should be high because of the routine tasks designed into the day-to-day operation of the new manufacturing process. Decentralization should be instituted at this level, because the operational requirements of the new manufacturing process requires decisions made at this level, and not at any level higher than this in maintaining and supporting the new process.

During the production and construction phase of the new manufacturing process, the design engineers and the plant personnel will jointly participate in designing the human centered work system. This entails designing a job that justifies using a person, rather than a job that merely can be done by a human.

For example, the work system of the metal forming system must be ergonomically designed for monitoring and correcting the process during its operation. When the metal forming system jams, the operator should be able to safely enter the machine and easily clear the jam. The operator should then return to the work system and easily put the metal forming system back into production. This method of function and task allocation makes full use of the human skills and at the same time compensate for human limitations. As the operator learns the system over time, intuition and judgment will intrinsically motivate the operator to improve the process by him or herself, or with the help of the design engineer. This nature of the work itself should lend itself to other internal motivational influences. The left over functions are then allocated to the computers within the work system that handles the mundane or repeatable functions and tasks of the metal forming system.

Measurement Phase

After the production and construction phase of the Sociotechnical Systems Analysis and Design has been completed, the next phase is the measurement phase of the STS. This phase specifically focuses on measuring the extent to which performance improved technically and socially.

Sociotechnical Systems Analysis and Design performance criteria mainly pertains to productivity, quality of work life, and safety (i.e. balancing the technical and social subsystems).

Hendrick [5] had stated that open systems (STS is an open, dynamic system) require monitoring and feedback mechanisms to follow and sense changes in their relevant task environments, and must have the capacity to make responsive adjustments. The survival of an organization depends on its ability to adapt to its external environment, through it's people.

The new metal forming system will be measured by the following Sociotechnical system and operational performance criteria of productivity, quality of work life, and safety:

- *Productivity* will be measured as a function of the output compared to the input, in terms of: a given period of time, quality, effectiveness, and efficiency. Were more quality cans being produced as expected?
- *Quality of Work Life* will be measured as a function of turnover, absenteeism, job characteristics, conditions, pay benefits, and leadership. Were the plant people who were maintaining and supporting this new process, meet the expected "well being" of

the person? Did the new process incorporate a humanized work system? Did the new system provide a healthy and safe working environment? Did the new system achieve greater employee commitment with their job?

- *Safety* will be measured in terms of accident reports relating to operation and maintenance to the system. When the operator clears jams, is the system safe for the person to intervene? Is the system built to National safety design guidelines?

The monitoring and feedback of the above performance criteria's will be evaluated continuously and adjustments will be made accordingly in assuring that the Sociotechnical Systems Analysis and Design approach is deployed and implemented correctly, as planned, as scheduled, and on time. When a change from the external environment occurs, the new Sociotechnical Systems Analysis and Design, manufacturing process design will adopt the change through the people [1].

The organizational dimensions of this phase entails low horizontal differentiation, high vertical differentiation (levels of information need to be sent up in the hierarchy levels), and little integration. Formalization is high, because of the routine tasks involved with the measurement phase in constantly monitoring and giving feedback to the people in maintaining and supporting this metal forming system. Decentralization is also high, because the decisions must be made at the plant level if the process varies out of control and must be corrected and stabilized.

In this phase the allocation of functions process is to iterate the design cycle of the allocation of functions process to correct errors, optimize the design and complete the design to an acceptable level of detail [13]. For example, if the results of the downtime of the manufacturing process stated previously in the production and construction phase are above acceptable levels, more emphasis must be allocated to the operator in training to become more familiar with the manufacturing process in order to better understand, troubleshoot, and fix the problem and get the manufacturing process back into operation. If the spoilage or bad product measures are higher than the acceptable levels, more emphasis must be allocated to the operator in terms of cognitive support, like computerized workstations at the manufacturing process for monitoring the product (cans) measurements real-time. This will allow the operator to be actively involved with the manufacturing process and keep his/her mental model updated on how the manufacturing process is behaving.

Evaluation Phase

After the measurement phase of the Sociotechnical Systems Analysis and Design has been completed the next phase is the evaluation phase of the STS. Were the following outcomes realized?

- Was performance improved *technically*? Productivity should have exceeded everyone's expectations and goals. Dramatic improvements should have been made, which will result in the organization achieving it's business goals in the scheduled implementation time.
- Was performance improved *socially*? Quality of work life, employee "well being", should have exceeded everyone's expectations and goals. The Sociotechnical Systems Analysis and Design approach should produce a fully harmonized system that produced a humanized work system, in creating a healthy and safe quality of work life, while achieving greater employee commitment.

The organizational dimensions pertaining to this phase entails low horizontal differentiation (i.e. no specialty areas required and based on the minimal number of occupational specialists and low level of training involved), low integration (because of low horizontal differentiation, meaning there is little involvement with communication, control and coordination due to the minimal amount of horizontal differentiation or departments required in this phase), and high vertical differentiation (i.e. need to pass the information to the higher levels, the number of levels separating the chief executive from the employees working directly on the systems output, and the increased levels of the span of control is required in operating the new process). Formalization will be low because the people involved at this level will be mature, experienced and professionalized. When the professionalism is high, the formalization will be low. Centralization is high because decisions made to the process should be made outside of the daily operations of the new process (strategic decisions relating more to the organization/machine level than the human/machine level).

The outcome of both the technical and social subsystems being optimized in producing a quality work system proves that *joint optimization* was realized. Applying this performance improvement process to other areas of the company will make the company better overall.

VALIDATION

How would I test the Sociotechnical Systems Analysis and Design approach with the metal forming selection and design application? The type of research I propose is experimentation. "There are no clear simple fundamental laws of nature, but nature is a complex system that will never be fully understood. The job of science is to provide models of nature which approximate the behavior of the natural system [11]." Experimentation is a process with an emphasis on model formulation and development. The model formulation that was developed is the Sociotechnical Systems Analysis and Design approach. Figure 11 illustrates the experimentation research that will be used in the validation plan [11].

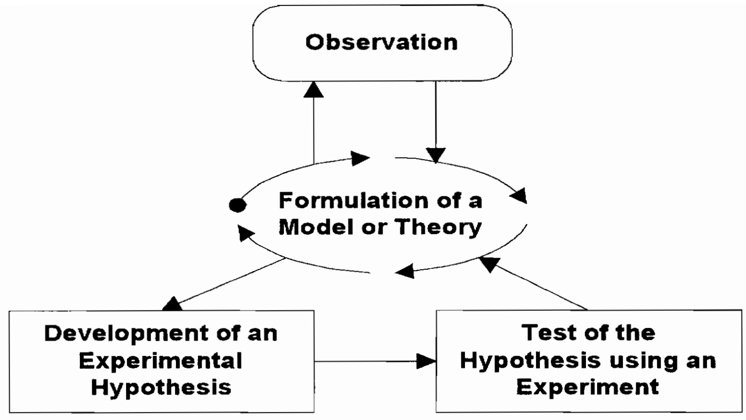

Figure 11. Experimentation research model.

The Sociotechnical Systems Analysis and Design provides the theory necessary to implement experiments to form closure in answering research questions. Experiments can be performed by applying different external environments (dynamic and stable over time type of environments) to the STS. Due to joint causation, both the technical subsystems and the social subsystems respond to causes in the environment. Each type of environment will establish the different experimental hypotheses. Testing these hypotheses would entail experiments controlling the environment to be dynamic (i.e. changing the different types of specifications of the input material going into the metal forming system in a random or in a multiple fashion), or stable over time (i.e. changing the different types of specifications of the input material going into the metal forming process in a single, sequential fashion, one at a time. Change one specification of the material, test it, evaluate/observe it, then change a second specification, and so forth).

This iterative process of developing different types of environmental, experimental hypotheses based on the Sociotechnical Systems Analysis and Design, testing the hypotheses, and then accumulating the data to be used as information in the observation/evaluation phase of the experimental model, will provide internal validation to the STS.

An example of this proposed experimental design is to use some historical data collected at my company reflecting a technical-centered project, versus a social-centered project, and then hypothesize the Sociotechnical Systems Analysis and Designed project.

Figure 12 illustrates a technical-centered project concentrating on the technical subsystem and not considering the social subsystem.

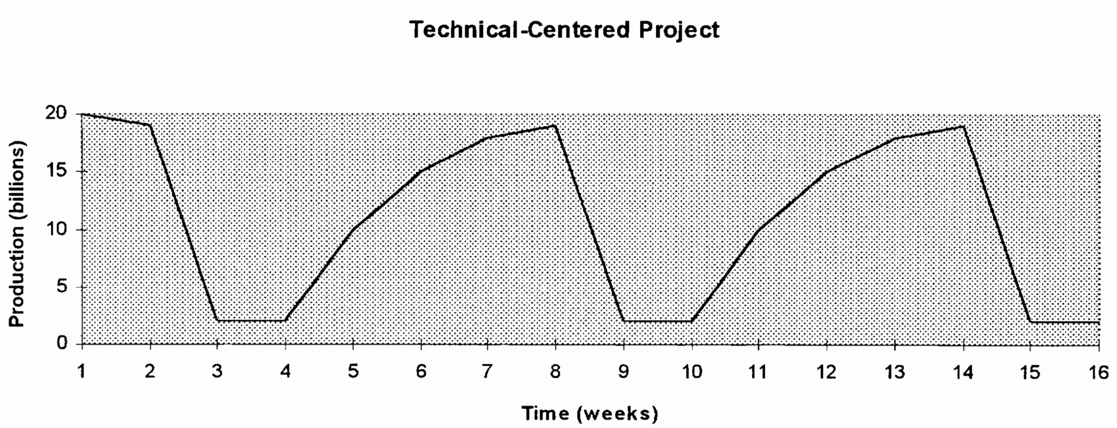

Figure 12. Technical-centered project.

In figure 12 time period #2 indicates when the existing manufacturing process curtailed its production to allow the new technical-centered project to be implemented at time period #4 into the can plant. The technical-centered process would come near the required production mark of 20 (time period #4 to time period #8), but would drop off drastically because of the high complexity of the system that caused the system to be hard to maintain and support (operator "well being" scored poorly). The social subsystem was suboptimized when the technical subsystem was optimized. This resulted in long downtimes and very short times of operating at the required production specifications.

Figure 13 illustrates a social-centered project optimizing the social subsystem and not considering the technical subsystem.

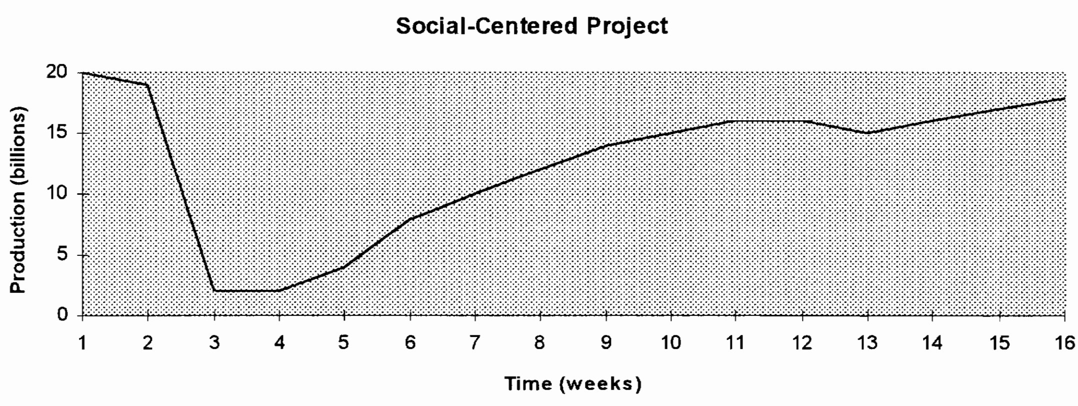

Figure 13. Social-centered project.

The outcome of figure 13, the social-centered project, resulted in production not meeting the required quota of the 20 mark in the desired amount of time. One of the problems with social-centered projects is the time required for systems to achieve order or self organization in order to naturally emerge out of chaos [1]. The change or chaos was when the social-centered system was implemented into the can plant at the time mark of 4. The social-centered system was easy to maintain and support, had very little downtime and almost all up-time (operator "well being" scored high), but the technical subsystem was not considered in achieving system performance requirements. The come up curve took too long (i.e. the production quota was not met, therefore some customers never got their full orders), there wasn't enough time for the process and the environment to adapt to it's natural order and principles. The company would have to intervene before the can plant could adapt to the change. Every time the system was shut off (due to breakdowns, jams, scheduled maintenance days, etc.) the come up curve took too long, production quotas were not met and customer orders were not fulfilled.

Figure 14 illustrates an Sociotechnical Systems Analysis and Designed project, jointly optimizing the technical subsystem and the social subsystem with respect to the external environment that both subsystems operate within.

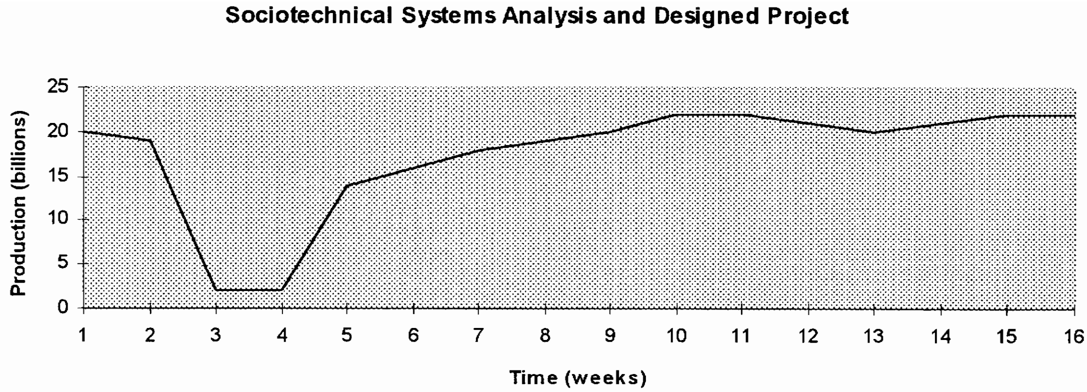

Figure 14. Sociotechnical Systems Analysis and Designed project.

Again, at time period #2 the existing manufacturing process curtailed its production in order for the new STS manufacturing process to be implemented at time period #4.

The result of the Sociotechnical Systems Analysis and Designed project was very little down time, allot of up-time, achieving the required production mark of 20, and *beyond that mark*. The technical subsystem achieved system operational and maintenance requirements (production and product specifications) and the social subsystem achieved high marks for the operator "well being" requirements.

The outcome of this *Sociotechnical Systems Analysis and Design* approach is to develop a process that will humanize the work system, in creating a healthy and safe quality of work life, while achieving greater employee commitment, and at the same time reducing related costs and achieving the productivity and specification requirements.

CONCLUSION

The Sociotechnical Systems Analysis and Design approach is an excellent process in selecting and designing the preferred manufacturing system. By jointly optimizing the technical and social subsystems, with respect to the environmental subsystems, one can select and design a fully harmonized system. This top-down assessment driven, human-centeredness design approach utilizes the macroergonomic (organization/machine, joint participation) design implementation, which prescribes a participative approach to the microergonomic design interventions. The microergonomic level covers the second generation of ergonomics (user-friendly/system interfaces) and the first generation ergonomics (human/machine interfaces). This process answers the problem of this project and report of "How do you select and design the preferred manufacturing process?"

The Sociotechnical Systems Analysis and Design approach also satisfies the deficiency of not considering all three subsystems (technical, social, and environmental) when new designs are developed, the outcome are suboptimized systems; i.e. one tends to optimize the technical subsystem without even thinking of the social subsystem, or vice versa of optimizing the social subsystem without even thinking of the technical subsystem with respect to the environment that both subsystems exist and operate within. Sociotechnical Systems Analysis and Design using joint participation and joint design in achieving joint optimization will satisfy this project and report's deficiency statement.

Table 3 lists the key features of the Sociotechnical Systems Analysis and Design approach in selecting and designing the preferred manufacturing process.

Table 3.

Sociotechnical Systems Analysis and Design in Selecting and Designing the Preferred Manufacturing Process

Methods:	Top Down; Open System; Joint Causation; Joint Participation; Joint Design; Joint Optimization; Harmonized System of the Technical, Social, Environmental, and Organizational Subsystems.
Level of Analysis:	Organization/machine Interface (3rd generation of ergonomics); User-Friendly/System Interface (2nd generation of ergonomics); Human/Machine Interface (1st generation of ergonomics)
Focus:	Transform an operational need into a system configuration in achieving Joint Optimization (Macroergonomics prescribing a participative approach to Microergonomics) by using the Joint Causation, Joint Participation, Joint Design methods.
Expected Results:	Dramatic Performance Improvements when Joint Optimization is realized (i.e. productivity, employee well being and safety measures were achieved).

In summarizing the approach used in this project and report, the Systems Engineering Process was used to describe the overall system in terms of an input/output illustration and an hierarchy of the systems involved within the can plant. The system operational requirements and maintenance concepts were developed to perform a functional analysis in terms of operational and maintenance functional flow diagrams. The functional flow diagrams then delved down to the problem level and deficiency area.

The Sociotechnical Systems Analysis and Design was then used to prescribe the selection and design of the preferred optimum manufacturing process, with the objective of achieving joint optimization of a harmonized system.

RECOMMENDATIONS FOR FUTURE PROJECTS RELATING TO THE SYSTEMS ENGINEERING PROCESS

In developing future can plant projects relating to the Sociotechnical Systems Analysis and Design approach with the Systems Engineering Process, one would prescribe more potential performance improvements. This would entail utilizing the SEP as a *platform*, and then *launch* the macroergonomics, analysis and design of prescribing the participative approach to the microergonomics level as a foundation for achieving joint optimization of the Sociotechnical System for the can plant.

For example if the performance measures were innovation, operator well-being, and safety (and the need was defined to implement this project) one could prescribe a project of developing innovative concepts in a humanized work system in transferring the cans from the metal forming process downstream to the light tester system. In discovering, inventing, endorsing creativity, and putting ideas into action of these innovative concepts, one would use the SEP to establish the system operational and maintenance concepts of the desired transferring system of the manufacturing process, and then delve down to the problem area of the existing transfer system to determine the fundamental problem and deficiency areas already existing with the current transfer system. Then use the Sociotechnical Systems Analysis to determine the possible, potential, optimum innovative concepts, for a humanized work system, which would later be developed into transfer system alternatives.

Taking a new perspective for recommending future projects would use the Applied Systems Dynamics modeling technique to validate the Sociotechnical Systems Analysis and Design approach instead of using experimentation. This validation can be accomplished by developing a verbal description (qualitative analysis), followed by a causal diagram (model), and then utilizing system dynamic equations (quantitative analysis) to justify the STS Analysis and Design approach, versus a technical- or social-centered approach. One would use the technical-centered approach as variable A, the social-centered approach as variable B, and the STS Analysis and Design approach as variable C. Couple these three variables with the appropriate positive, negative, open and closed loop, first and second order differential equations, one could model the production output versus time of all three approaches at once to validate the STS Analysis and Design approach with respect to the technical-centered and social-centered approaches.

APPENDIX

DEFINITIONS

Sociotechnical System Theory involves a systematic analysis of the key characteristics of the organization's technology, personal subsystem, organizational structure, and external environment [1,5].

Systems Engineering Process is the definition of the problem and identification of the need; feasibility analysis; operational requirements; maintenance concepts; functional analysis and allocation; and preparation of the system specifications [2].

A *System* constitutes a set of interrelated components working together with the common objective of fulfilling some designated need [2, & Deming].

The *Systems View* is a network of interdependent components that work together to accomplish a common aim (W. Edwards Deming).

Ergonomics or *human factors* pertained primarily with human physical and perceptual characteristics. This was considered as the first generation of ergonomics, which led to the development and application of human-machine interface technology [5].

Table 4 illustrates the optimal organizational dimensions required for the Sociotechnical Systems Analysis and Design approach to deploy and implement the new manufacturing process in this project and report.

Table 4.

Organizational dimensions of the Sociotechnical Systems Analysis and Design approach

Assessment Phase	Complexity: low horizontal differentiation, high vertical differentiation, low integration. Low formalization. Centralization.
Preliminary Joint Design and Development Phase	Complexity: high horizontal differentiation, low vertical differentiation, high integration. Low formalization. Decentralization.
Joint Design and Development Phase	Complexity: high horizontal differentiation, low vertical differentiation, high integration. Low formalization. Decentralization.
Production and Construction - Joint Participation of Function Allocations	Complexity: low horizontal differentiation, high vertical differentiation, low integration. High formalization. Decentralization.
Measurement Phase	Complexity: low horizontal differentiation, high vertical differentiation, low integration. High formalization. Decentralization.
Evaluation Phase	Complexity: low horizontal differentiation, high vertical differentiation, low integration. Low formalization. Centralization.

Microergonomics pertained to the first generation of ergonomics, as well as the second generation of ergonomics, which pertained to the way people think and process information. This was focused on the cognitive nature of the work. This led to the development and application of the use-friendly/system interface technology [5].

Macroergonomics is the third generation of ergonomics, which pertains to the overall sociotechnical system level. It is concerned with ergonomics research, development and application of organization/machine interface technology [5].

Joint causation pertains to the way the technological subsystem and personnel subsystem interact with one another at every human-machine interface. Thus, they are interdependent and operate under joint causation, meaning that both subsystems are affected by causal events in the environment [6]. Joint causation refers to the notion that the social and technical subsystems are both affected by the environment [1].

Joint optimization pertains to optimizing both the technical and social subsystems together, this is the goal [1,6].

Joint design is the method by which joint optimization is achieved [1,6].

Deengineering is redesigning organizations according to natural order and principles so they can be continuously responsive and adaptive (1,4).

Performance means an integrated relationship among seven dimensions: effectiveness, efficiency, quality, productivity, quality of work life, innovation, and profitability/budgetability. *Effectiveness* is a function of rightness, timeliness, accomplishment, output, outcomes, and quality. *Efficiency* is a function of inputs/resource consumption, budgets, time, quality, and actual resource consumption. *Quality* is a function of perception, requirements, process capability, discipline, caring, and engineering and design. *Productivity* is a function of output compared to input for a period of time, quality, effectiveness, and efficiency. *Innovation* is a function of creativity, reduction to practice, teamwork, driving out fear, and ideas put into action. *Quality of work life* is a function of affects, turnover, absenteeism, job characteristics, conditions, pay, benefits, and leadership. *Profitability* is a function of revenue and costs. *Budgetability* is a function of what was promised versus what was delivered and budget versus actual costs [8].

Organizational dimensions of macroergonomics pertains to the structure of the organization, including how it is managed, may be thought of as having three major components: complexity, formalization, and centralization [5].

Complexity refers to the degree of differentiation and integration that exist within an organization. Three major kinds of differentiation exists within an organization. The three major kinds of differentiation that are inherent within an organization structure are: horizontal differentiation, vertical differentiation, and spatial differentiation [5].

- *Horizontal differentiation* refers to the degree of departmentalization and job specialization that is defined into the organization.
- *Vertical differentiation* refers to the number of hierarchical levels separating the chief executive position from the jobs directly involved with the system's output.
- *Spatial differentiation* is defined as the degree to which a location of an organization's facilities and personnel are dispersed geographically from the main headquarters.

Formalization is defined as the degree to which jobs within organizations are standardized [5].

Centralization refers to the degree that formal decision-making is concentrated in an individual, unit or level (usually high in the organization) thus permitting employees (usually low in the organization) only minimal input into decisions affecting their jobs. *Decentralization* is preferred (a) when operating in a highly unstable or unpredictable environment, (b) when the design of a given manager's job will result in taxing or exceeding human information processing, and decision-making capacity, (c) when more detailed "grass roots" input to decisions are wanted, (d) for providing greater input to employees by allowing them to participate in decisions that affect their jobs, more fully utilize their mental capacities, and increase their sense of personal control and psychological significance to the organization, (e) for gaining greater employee commitment to, and support for decisions by involving them in the process, and (f) for providing greater training opportunities for lower-level managers. [5].

Technical performance measures relate to performance factors (range, accuracy, input/output, weight, size, etc.); availability factors (probability of being available); reliability factors (MTBF, R, lambda); maintainability factors (MTBM, MDT, Mct, MMH/OH); human factors (personnel skill/quantities); logistic support factors (supply/inventories, test equipment, personnel and training, transportation, facilities, data, computer resources); and economic factors (life-cycle cost) [2].

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