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A Decision Support System for New Vehicle Launching: A Conceptual Framework

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Abstract: This study deals with the conceptual design of a computer-based Decision Support System (DSS) to assist in the launch process of a new vehicle production line, as well as to promote the achieving of pre-established quality objectives throughout the vehicles' life cycle. The system identifies workstation constraints for continuous improvement in all body, paint and assembly shops and enhances the planning and execution of vehicle model mix scheduling to enable a level process balance for production. This includes understanding the impact of model and option mixes at each workstation and developing vehicle scheduling parameters. The end result is a higher vehicle quality due to a smoother workflow and more consistent work pace for the production team members.

Key words: Decision Support System (DSS), vehicle production, paint, assembly shops, scheduling

INTRODUCTION

Synchronous Product Flow (SPF) or Continuous Flow Manufacturing (CFM) is a philosophy which concentrates on maximizing throughput while simultaneously reducing inventory and operating expense (Shah and Ward, 2003). CFM is a common sense approach that concentrates on turning raw materials into finished products as quickly as possible and with no wasted effort. It focuses on improving production process bot-tlenecks (i.e., constraints) to the exclusion of all other improvement efforts. Every shop has bottlenecks or constraints in some form. A constraint is defined as any element of the production system that prevents the system from achieving the goal of making more money (Martinelli *et al*., 2001). Alternatively, Grub (2005) defined a bottleneck as a constriction that limits an organization's ability to reach its goals. There are typically a small number of constraints in any production system that limits its current performance. Some bottlenecks are machine or process related and they take form on the shop floor. Others are organizational and can be more obscure to identify (Grub, 2005). In the manufacturing world, bottleneck implies a resource that is physically restricting production. Understanding and managing the bottlenecks within a system can better optimize assembly line efficiency and throughput (Stein, 1997; Rosar, 1998).

For a shop that produces only a single product, the task of identifying constraints is usually simpler than that of a shop producing a variety of products. The constraints for the shop producing multiple products can move from location to location, based on the product being produced. To effectively attack and remove these constraints, it is imperative that the single most influential constraint is identified and then corrected at which time the primary constraint for the process will move to another point in the process. The primary constraint represents the least productive point in the process (Grub, 2005). Constraints that commonly influence production lines include (Rosar, 1998):

- Machine capability upgrades
- Machine configuration changes
- Multi-product operations
- Machine reliability specifications
- Environmental changes
- Maintenance
- Personnel
- Input/output equipment feeding placement equipment

A common term applied to the process of identifying bottlenecks and dealing with them is the Theory of Constraints (TOC). Goldratt in his book "The Goal",

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discusses the theory of constraints and defines a 5 step process of continuous improvement to correct constraints (Goldratt, 2004; Goldratt *et al*., 2000; Goldratt and Goldratt-Ashlag, 2010; Woeppel, 2010):

Identify the manufacturing process constraint: A constraint must be identified and understood before it can be corrected. This is typically a physical constraint (requiring additional capacity) or policy (requiring modification of an erroneous policy), although a complete list of constraint classes may include marketing, material, logistics, management and organizational behavior issues. Typically, the machine with the lowest overall production capability is the major production constraint.

Exploit the manufacturing process constraint: Concentrate on the primary causes and formulate a plan to rectify them. All efforts must be taken to maintain the productivity of the constraint. This could mean increasing the staffing for the constraint, operating the constraint on increased or additional shifts or placing quality checks upstream of the constraint to ensure that the constraint always works with quality parts.

Subordinate everything else to the constraint: Removing the bottleneck must be the primary objective of everyone that is part of the solution. Other operations should be scheduled so that the constraint is always operational. If the constraint can only process one hundred units, there is no need for other resources to process more. The factory must adjust other machine operations and logistics moves so that the constraint is always loaded and operational.

Elevate the constraint: This is accomplished only if researchers are unable to break the constraint in the first 3 steps and involves spending money to elevate the capacity of the constraint to a level at which it is no longer the constraining subprocess in the system. Investments, such as equipment upgrades or additional capacity should be made to improve the capacity and throughput of the constraint. The key is to elevate the constraint until it is no longer constraining the operation.

Repeat the process: Once the current constraint is removed, operations should be stabilized and throughput reexamined in order to identify any new constraints requiring upgrading. The elimination of one constraint will uncover another. The theory of constraints process should be repeated on the new constraining operation. Frequently, these opportunities become apparent while working on steps 1-4. Thoroughly studying a process, constraint may reveal several contributing causes all of which must be corrected. Understanding, all the causes of the constraint allows for a correction plan to be formulated and implemented which will rectify any causative influence that is restraining production (Grub, 2005).

In addition to performance constraints, cost constraints are involved with eliminating bottlenecks. Amending a bottleneck should be compared with the cost required to implement the change. The costs to modify equipment, add new equipment or add personnel should be compared against the potential profit gained due to production increases (Rosar, 1998). If the costs outweigh the profit gains, analysis of less costly process improvements to reduce the effects of the bottleneck should be considered.

In conclusion, the challenge of identifying and solving constraints is never-ending, for by nature, constraints move somewhere else (Grub, 2005). The commitment to continuous improvement is essential and the knowledge of all causal factors is required in order to properly correct constraints.

COMPANY REQUIREMENT AND RESEARCH OBJECTIVE

The project was initialized to address the needs of a major automobile manufacturer. A series of interviews was conducted with plant personnel by the research team. Throughout the manufacture of the company's vehicles, it was determined that that there was no systematic approach to identify shop floor production constraints to proactively plan for model mix variations. Each process engineer or group leader identified constraints in discrete ways which seemed to work best for each individual. This resulted in a lack of consistency. Frequently, constraints were realized as they occurred on the production line. The organizational commitment to shop floor support and teamwork by the company facilitated the prompt establishment of countermeasures to either eliminate the constraint or to develop contingency plans. Due to the planned expansion of the number of number of vehicle models to be manufactured at this facility, as well as the upcoming increase in production volumes, a customized, computer-based approach was needed.

Although, standard time and line balancing systems are commonly used in automotive manufacturing facilities, elemental standard time studies and line balancing functions alone are not sufficient for an effective production and planning control of the floor shop (Moynihan *et al*., 2002; Palmetier and Crum, 2002). Decision Support Systems (DSS) are software systems that utilize sophisticated algorithmic approaches to address problems. A DSS that can readily identify specific vehicle model and option constraints, based on changing customer demand rates on manufacturing operations would better accomplish such an endeavor. That is why, the researchers aimed at the development of a methodology for the manipulation of workstation process sequences and times and vehicle option percentages to be implemented via a computer-based decision support system.

A CONCEPTUAL DSS FOR AUTOMOTIVE MANUFACTURING

The conceived DSS architecture allows the successful identification of existing workstation constraints, as well as potential workstation constraints from proposed customer demand rates. The analysis of the constraints provides a basis for continuous improvement activities and the development of vehicle scheduling parameters. The system encompasses the following functions:

- Be easily maintained as a floor-based system by production team members
- Document the sequence of production operations and corresponding times per the standardized work document
- Identify and provide analysis of the specific model and option constraints at each workstation and line/area
- Identify and provide analysis of the required direct labor time to satisfy the average model mix at each workstation and line/area
- Provide documentation of the direct labor time to build corporate defined standard vehicle models and options
- Document the history of direct labor time required to produce standard models and options
- Capture the time-documented impact of continuous improvements, engineering changes and rebalance activities on production operations
- Provide what if scenario capability to access the impact of new or proposed customer demand rates on production operations
- Allow for a system administrator to create and modify user profile and screen access administration
- In addition, the study included the development of the overall information process flow which incorporates the human interaction with the computer-based system, necessary to achieve the aforementioned objectives

It must be noted that the designed system has some limitations. The system relies on the documentation of workstation process steps and times after a process is changed and implemented on the shop floor. The system can only evaluate the impact of current and future model mix information on established processes and identify the need for changes.

The software architecture does not consider impacts to forthcoming workstation processes until they are already realized on the shop floor and entered into the system. In addition, the software is not a real time system. The capability to identify and understand the process constraints is present but a real-time warning is not within the software capabilities at the moment in time when the constraints are occurring. To achieve the functionality of a real-time warning system, a direct interface with the shop floor monitoring system would be required.

As previously stated, the main objective of this effort was to design a computer-based decision support system to identify shop floor workstation constraints. Included in the system design is an overview of the system software, as well as a condensed version of the detailed functional specifications. Throughout the rest of this manuscript, the conceived DSS is referred to as the Time Analysis System (TAS).

In order to achieve the aforementioned functionality, the TAS utilizes a collection of inputs to produce specific outputs. The development of vehicle scheduling parameters to ensure a smooth workflow and consistent work pace for the production team members is then possible. Further, the accumulation of standard labor times required to build defined vehicle models and options which is needed for financial reporting and planning can be accomplished. The main inputs to the system are listed as follows:

- Process steps and times for each workstation
- Definition of all plants, shops, lines/areas and stations that form the complete plant structure
- Definition of vehicle types and their shop relationships
- Vehicle type and option percentages to create the model mix in each shop
- Future vehicle type and option percentages (what-if model mix scenarios) for each shop
- Model mix parameters that restrict infeasible option combinations to be included together
- Definition of base or standard models and included options for financial reporting
- Direct labor time required to produce standard models and options at the start of production operations
- User profiles and accounts

The following are the main outputs from the TAS:

- Station model mix impact report; documents the sequence of operations and corresponding times and graphically illustrates the model/option constraints for the station
- Model constraint analysis report; graphically illustrates the model/option constraints for a line/area of a specific shop
- Time constraint analysis report; graphically illustrates the weighted average time of each workstation in a line/area of a specific shop in relation to the line speed
- Direct labor report provides the utilization percentage for each team of a line/area and the required direct labor to satisfy the average model mix
- Finance report provides the direct labor man hours to build defined vehicle models and options
- Process change impact reports summarizes the time documented impact of continuous improvements, engineering changes, new model introductions and rebalance activities on the shop floor
- What-if scenario reports provides station model mix impact, model constraint analysis, time constraint analysis and direct labor reports based on future model/option mix projections

Figure 1 displays a node diagram that illustrates the relationship between the main system inputs and outputs. The system information flow begins in Fig. 2 with a vehicle design change in either the form of an engineering change or new model change sent from production control to process engineering. As it was mentioned before, an engineering change is defined as a product change that occurs during the current model year and a new model change is defined as a product change included in a collection of changes that are implemented for the new upcoming model year.

Process engineering evaluates the process impact of the design change and decides if further actions are required. If the process is impacted, the change is reviewed with the production launch team who simulates the change in an offline training area and develops the initial standardized work. The launch team is a small group of production team leaders that are responsible for understanding and simulating upcoming product changes, training the production team members on the future changes and assisting with on-line continuous improvement and rebalancing activities. Simultaneously to the launch team's actions, process engineering develops the process design sheet which officially documents the change from a design standpoint. The results of the off-line process simulation and the process design sheet are communicated to the responsible production group leader and team leader. The group and team leader with assistance from the process engineer, develop and trial the on-line integration plan to accommodate the change. Depending upon the nature of the change, the plan development may involve the update of other documentation and include communication with the quality department. At this point in the flow, a rebalance or continuous improvement activity, prompted from an engineering analysis of the time analysis system outputs can also initiate a plan and on-line trial. This methodology is expanded upon when the later portion of the flowchart is explained.

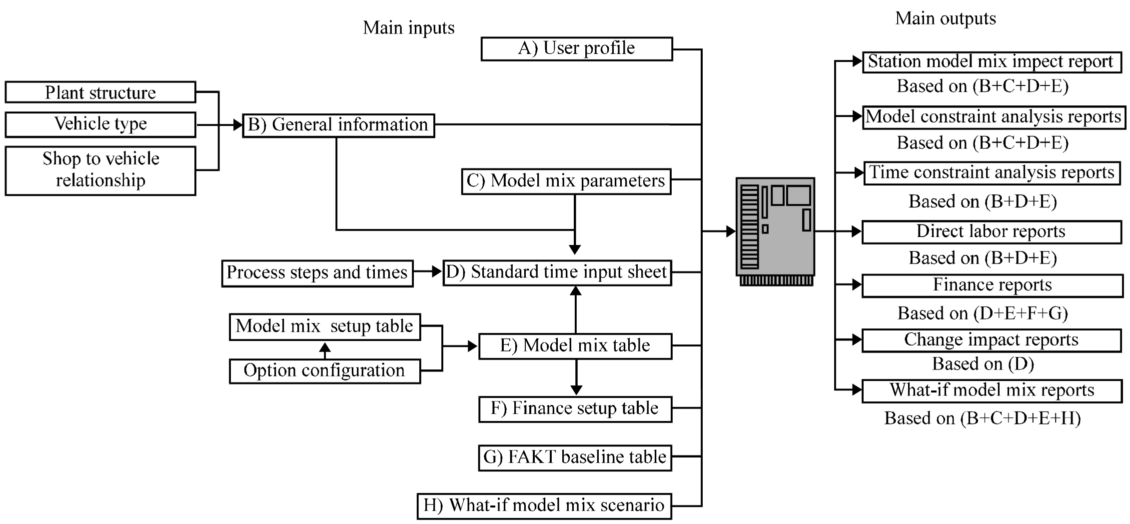


Fig. 1: System inputs and outputs relationship diagram

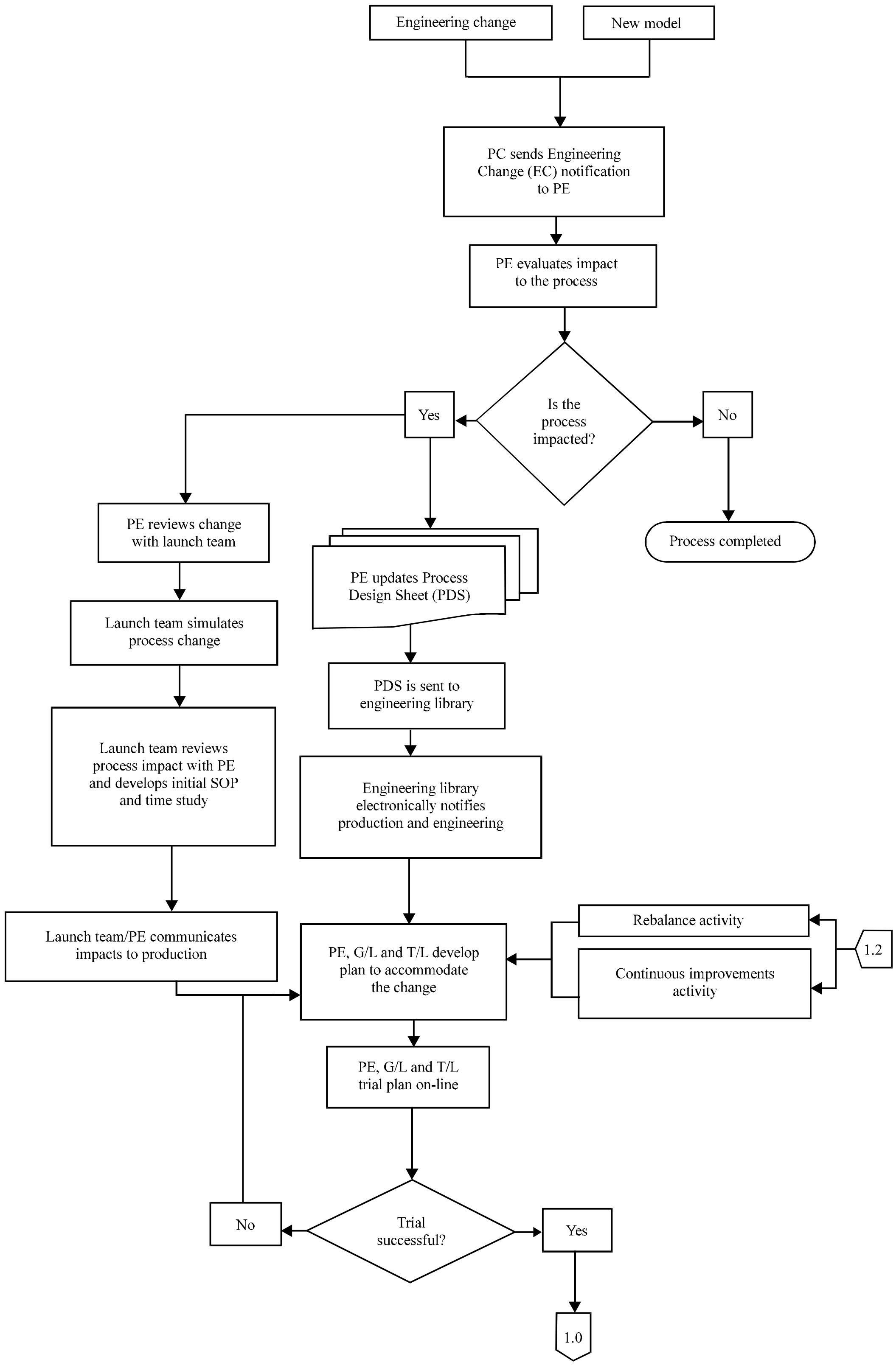
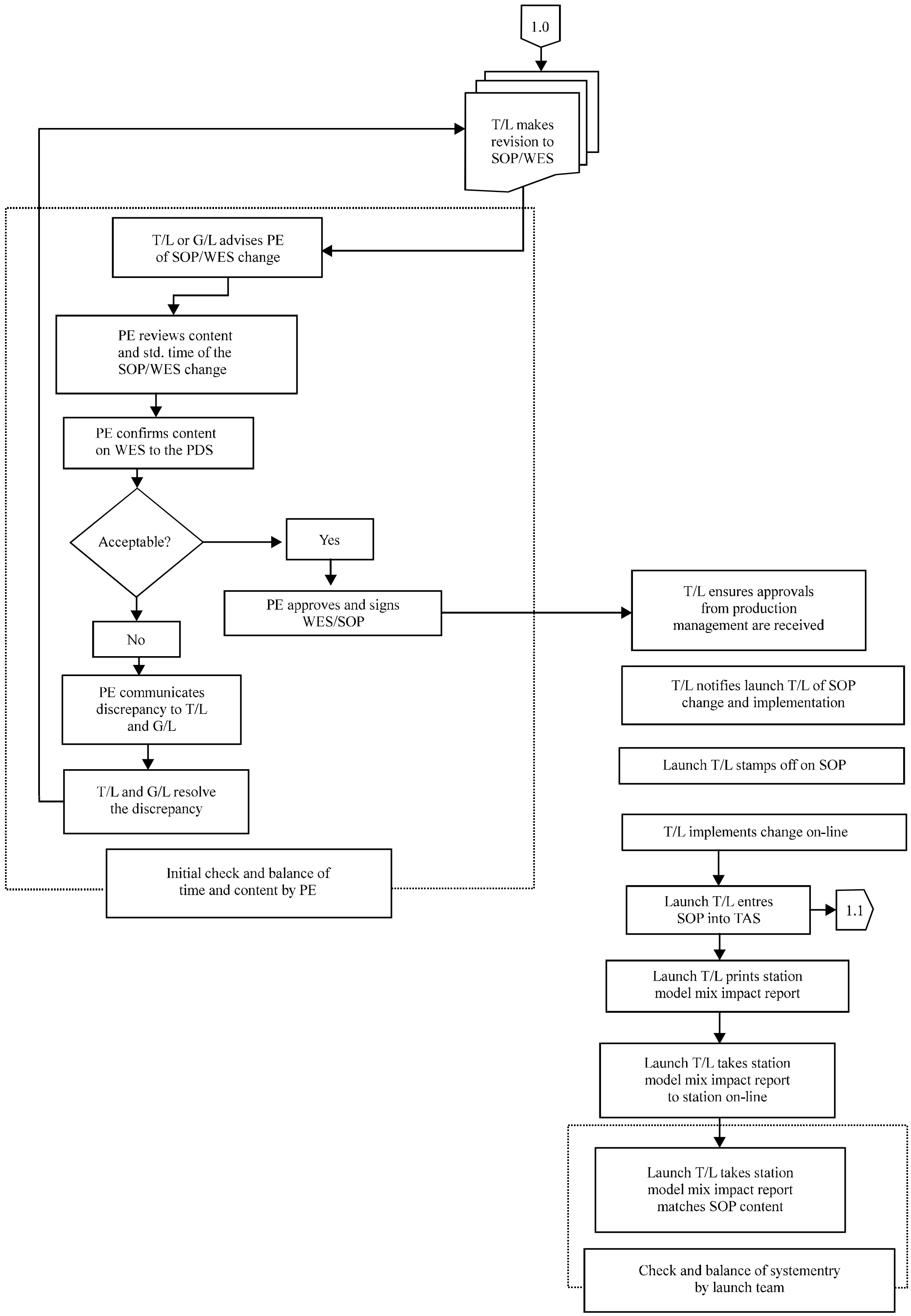


Fig. 2: Continue



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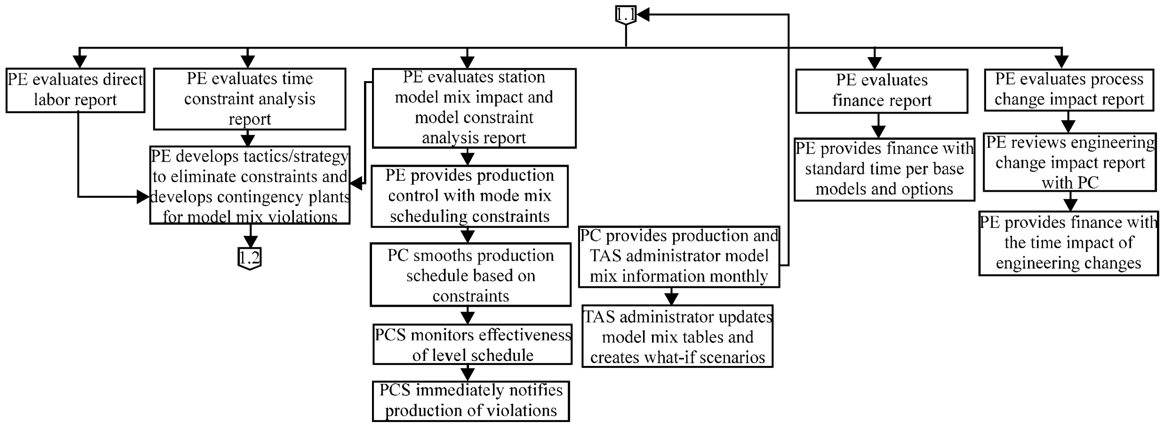

Fig. 2: Overall system information flow

Pending the success of the on-line trial, the team leader revises the affected work element sheets and standard operating procedures in preparation for the official implementation. The process engineer reviews the Work Element Sheet (WES) and the Standard Operating Procedure (SOP) for accuracy of the process steps and times. Any inadequacies discovered by the process engineer are communicated to the team leader and group leader for resolution. The process engineer approves and signs the documents after he or she is satisfied with the content. This review process by process engineering is a check and balance of production's standardized work and it is extremely critical in maintaining accurate process steps and times. Once all remaining approvals from production management are received, the team leader notifies the launch team leader. The launch team leader stamps the SOP document to acknowledge receipt and the team leader officially implements the process on the production line.

The direct interface to the time analysis system begins as the launch team leader enters the process steps and times from the SOP into the standard time input screen of the time analysis system. The launch team leader, after the system entry, prints the station model mix impact report, provides the report to the station on line and confirms that the content of the report matches the content of the SOP document. Once a station's SOP is entered into the time analysis system, process engineering has the ability to evaluate all system reports. The station model mix impact and model constraint analysis reports are used to identify and provide model mix scheduling constraints to production control. Production control smoothes the vehicle production schedule based on the constraints and monitors the effectiveness of the level schedule. In the case of a violation of a scheduling constraint, production control immediately notifies the appropriate production personnel. The station model mix impact, model constraint analysis, time constraint analysis and direct labor reports in summary, enable process engineering to develop the tactics and strategy necessary to eliminate identified process constraints. In addition, contingency plans are established for situations when a constraint cannot be eliminated and when the vehicle schedule cannot be leveled to prevent a constraint from occurring.

The tactics and strategy of the engineering analysis are realized in the form of continuous improvement or rebalance activities. Production control provides monthly updates to the vehicle type penetrations and option percentages that allow the TAS administrator to update the model mix tables and to create what-if scenarios. Changes to the model mix information can create changes in the process constraints which also initiates the need of the process engineering analysis of the system reports.

Process engineering provides the Finance Department with the standard times per base model and options via the finance report. Moreover, process engineering reviews the process change impact report with production control to highlight the time impact of engineering changes on the shop floor. Process engineering then provides this impact to finance for benchmarking and efficiency calculations.

HARDWARE AND SOFTWARE CONSIDERATIONS

The planned DSS software environment is server based and is graphically illustrated in Fig. 3. It was selected to both utilize the previously described logic flow and be consistent with the information infrastructure available at the client's site. The software database will be dedicated to a TAS application server that runs Windows

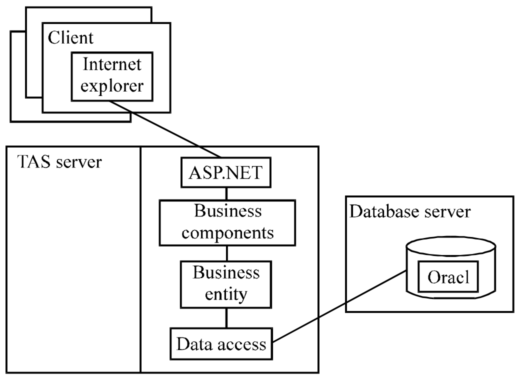

Fig. 3: TAS hardware/software environment

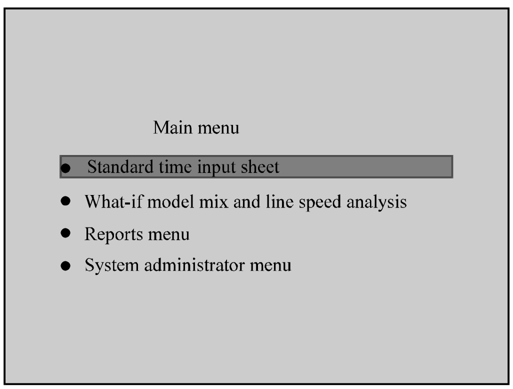

Fig. 4: Main menu screen

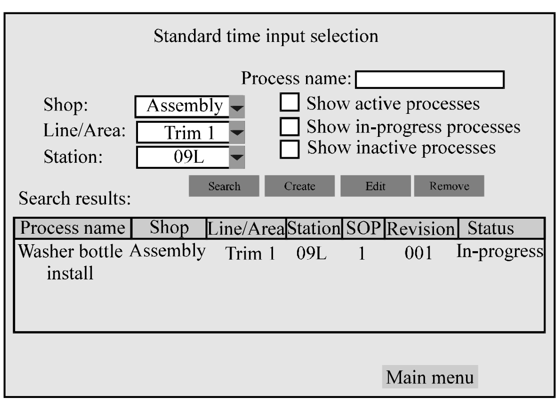

Fig. 5: Standard time input screen

IIS as the web server. This application server will connect with an oracle database server. The user interface will be web-based and the system will be accessed by users through individual Windows-based client workstations that have internet explorer installed.

Figure 4-7 depict sample screen shots from the conceptual DSS. From the main menu (Fig. 4), the user can input the assembly standard times, perform what-if scenarios, generate reports and input the project parameters and user profile data. For instance, if the user selects the standard time input option, Fig. 5 is display. When a what-if analysis is needed, a screen similar to that depicted in Fig. 6 shows up.

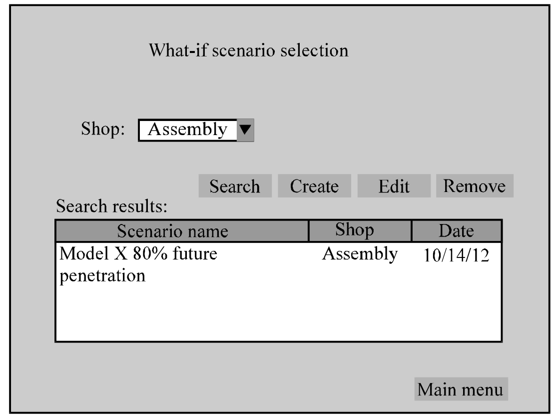

Fig. 6: What-if scenario screen

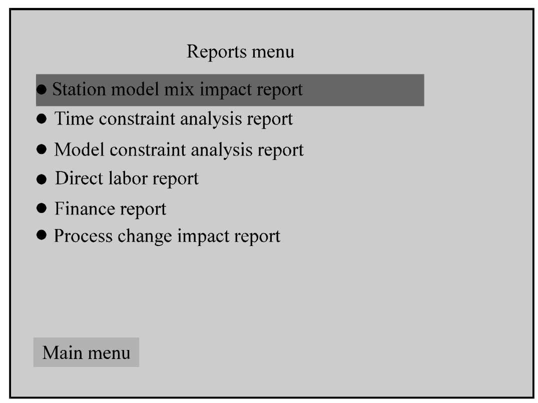

Fig. 7: Reports menu screen

The main outputs from the system (Fig. 7) comprise the station model mix impact report, the time constraint analysis report, the direct labor report, the finance report and the process change impact report.

Actual software development of the TAS system will be conducted by an outside contractor. The client has formal procedures for contractor selection including pre-bid specification review meeting with participating software companies, a pre-bid review and evaluation of submitted proposals, a decision meeting to select the preferred software developer, contract establishment with the chosen suppliant and subsequent physical development of the software.

CONCLUSION

This manuscript dealt with the design of a computer based decision support system to assist in identifying and improving upon shop floor constraints at a traditional automotive manufacturing facility. Included in the design was the development of the overall information flow required to support and execute the software system. The need for the conceptualization and development of a DSS with these characteristics was brought to fruition due to today's increased automotive-related product complexities which posed questions as to how effectively an automotive manufacturer can react on the shop floor to changing market demands.

The planned DSS architecture provides a number of benefits. The system imparts a systematic approach to problem solving of operational constraints. Option combinations that result in over-cycle conditions at workstations on the shop floor are identified and prioritized. This enhances the planning and execution of vehicle model mix scheduling to enable a level process balance for production. In addition, the outputs of system support the shop floor standardized work procedures and the systematic approach to continuous improvement.

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