A Model-Based Engineering Process for Increasing Productivity in Discrete Manufacturing

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Abstract

In a competitive market, manufacturing enterprises require a process of continuos, on-going improvement in order to maintain and enhance productivity and a competitive edge. The use of Information Systems (IS) has been increasingly playing a critical role in any such engineering process. The primary drivers are efficiency and quality increase through automation, facilitation of better business processes and improved decision making. The engineering process involves use of an IS for collection of relevant production data, visualization, analysis and decision making. Many problems and issues relating to the design, development, integration, evolution and maintenance of ISs in large-scale and complex plants have become apparent which are not adequately addressed by the traditional Process Monitoring & Control (PM&C) systems. Model Integrated Computing (MIC) [1] offers a feasible approach towards providing cost-effective development, integration, evolution and maintenance of ISs through the extensive use of models during the life cycle. This paper describes the application of MIC in the engineering process for improving productivity in the context of discrete manufacturing operations at Saturn. The Saturn Site Production Flow (SSPF) system is a client-server application, designed to provide an integrated problem-solving environment. It presents consistent and pertinent information, provides analysis and decision support services that are needed for informed decision making by the team members and leaders within Saturn.

1. Introduction

To remain competitive, manufacturing enterprises need to increase throughput while keeping the costs down at the same time. This requires day-to-day and long term examination and analysis of the functioning of the plant and operations, identification of bottlenecks in the production, analysis of capacity, etc., and identification of opportunities for improvements. This requires an engineering process for continuos on-going improvement. The engineering process would consist of gathering relevant plant data, visualization of plant operations and analysis of operations' capacities, bottlenecks, etc., followed by engineering and business decisions to improve throughput. In large-scale manufacturing plants, Information Systems (IS) play a critical role in this engineering process. However, traditional IS, including Process Monitoring & Control (PM&C)

systems have not been able to address the needs of such an engineering process due to many problems and issues relating to software design, development, integration, evolution and maintenance that have become apparent. The problems arise out of the scale and complexity of plants, the diversity of IS applications employed, and the tight interdependence between the two. Typically, there are a myriad of services that an IS uses for decision making needs to provide, such as monitoring, simulation, analysis, and business decision making. Model Integrated Computing (MIC) [1] offers a feasible approach towards providing cost-effective development, integration, evolution and maintenance of IS through the use of design-time models of the system to provide a common framework for different applications.

In this paper, we describe an engineering process for productivity and throughput increase in the context of discrete manufacturing operations at Saturn Corp. The Saturn Site Production Flow (SSPF) engineering process is designed to meet an initiative within Saturn Manufacturing to increase the number of cars built utilizing existing facilities and processes. The primary focus of tools and services provided by SSPF is the flow of material through the production facility. SSPF is intended to provide an integrated problem-solving environment which presents consistent and pertinent information, and analysis and decision support services that are needed for informed decision making by the team members and leaders within Saturn. The SSPF engineering process is supported by an IS called the SSPF system (in the following, the term "SSPF" will be used to refer to the engineering process as well as the IS, with the qualifiers "engineering process" and "system" added when necessary). We have used MIC technology to develop SSPF tools and services for modeling the plant data, visualization of operations and analysis.

Section 2 gives a brief description of the Saturn plant and the production flow. Section 3 discusses the SSPF engineering process and presents the application of MIC to SSPF. Section 4 discusses some of the experiences relating to deployment and use of SSPF.

2. Background

Saturn Corporation designs and manufactures automobiles. The manufacturing process involves many disparate operations such as stamping, molding, fabrication, casting, machining, assembly, etc., which are brought together into an integrated manufacturing system that is designed around "just in time" (JIT) principles.

The Saturn manufacturing plant can be viewed as consisting of processes and buffers. Processes represent the operations required for making a car. An operation can involve casting, machining, welding, etc., of car parts, or it could involve assemblies from, e.g., Transmission Assembly all the way to final car assembly. Associated with each process are certain measurements that relate to the productivity of the process. Examples of such measurements are : cycle-time, production count (how many parts were machined, assembled, etc.), Work In Process (WIP) (how many parts are currently being worked on), production downtime (equipment breakdown, etc.).

Buffers (or banks) lie between processes and hold parts and/or sub-assemblies, that are produced by an upstream process before they are consumed by a downstream process. In different sections of the plant, buffers take on different forms -- they may be Kanbans, conveyors, etc. However, the information that is pertinent for production is common to all buffers -- bank count (number of parts/sub-assemblies in the buffer) and the minimum and maximum capacities of the buffer.

The inter-connectivity of processes and buffers captures the sequence of operations required to produce a car, and the interdependence of processes on each other and on the buffer capacities. A process may have to remain idle due to the fact that an upstream process is not producing enough parts (this condition is called starving). On the other hand, a process may be forced to stop producing if a downstream process is not consuming enough parts (this condition is called blocked). The starving and blocked conditions may arise due to mismatches between cycle-times of processes, their WIPs, the capacities of buffers between them, and many other reasons.

The concept of production flow is concerned with the flow of material (raw materials, parts, sub-assemblies, etc.) through the processes and buffers, and encompasses all the production related entities of processes and buffers (e.g. production count, WIP, bank count, starving, blocking).

3. SSPF Engineering Process

The SSPF engineering process is an iterative process, which involves the following:

1. Model the production data, i.e., model the operations, buffers, production counts, etc., in the plant.
2. Collect the data in real-time and log it for later retrieval and analysis

3. Visualize the production flow for current (real-time) and historical data.
4. Use analysis and simulation tools to identify bottlenecks, etc.
5. Make business decisions regarding the throughput improvement.

The engineering process begins with modeling of production data. After that, the data is collected and stored. The current data and stored (historical) data is visualized and analyzed, leading to business decisions. At this point more data collection, visualization and analysis might be required before making any changes. If a decision is taken to change business practices to increase productivity, the changes may or may not need to be reflected in the data model. If the production flow or plant configuration is changed, the changes will need to be reflected in the data model.

The various tasks involved in the engineering process, as they relate to and IS, are discussed next.

4. Data Modeling

SSPF engineering process involves collection, presentation, storage, retrieval, and analysis of data. There is a data rich environment at Saturn based on traditional process monitoring and control (PM&C). There are an estimated 80,000 points of live data that are monitored. The data being measured consists of production count, downtimes, bank counts, and other production related information. The majority of these data points are provided by the Programmable Logic Controllers (PLCs) of machines. This data is collected, logged and presented to users on status screens that are configured using a data acquisition and display package called Cimplicity [2]. This architecture has been in place since start of production in 1990. However, in the absence of any data models to guide the data collection, logging and visualization, the enormous volume of data presents considerable difficulties in using the system for monitoring site-wide status and for performing simulations and other decision making analyses.

The shortcomings of the traditional IS arise out of the fact that the data collected by the PLCs is merely "raw" data. There is no context provided for the data which can associate with raw bits of data the semantics necessary to use the data well for the engineering process. In other words, what is needed is a model of the data. However, modeling the data itself is not enough, since the context of production data is the plant, i.e., the manufacturing processes, buffers, etc. Thus, in order to model the plant data, its semantics, and how it is to be used, one must model the plant itself. For SSPF, we have used MIC approach to model the plant and its data. Here we summarize the key modeling concepts that are used for defining the SSPF application.

The MIPS environment of SSPF allows the end-user to model the production flow at Saturn using a graphical model builder. The processes are modeled hierarchically, allowing abstraction of relevant production flow information at higher levels in the hierarchy. Figure 1 shows the model for Vehicle Initial Build, a section of the Saturn plant. The process Vehicle Initial Build has five sub-processes : Cockpit 100, Cockpit Test, Hardware 200W, Hardware 200C, Hardware 200E and Hardware 310 (not shown completely in the figure). The icons for the sub-processes can be seen in the figure. The interface points on the icons represent conveyor systems that deliver parts/sub-assemblies from buffers. The buffers between processes can also be seen (2200A, 2200B, 300, etc.). The production flow is represented by the connectivity between buffers and processes, as shown. There are many more types of models, aspects, properties and attributes which together comprise the SSPF modeling paradigm.

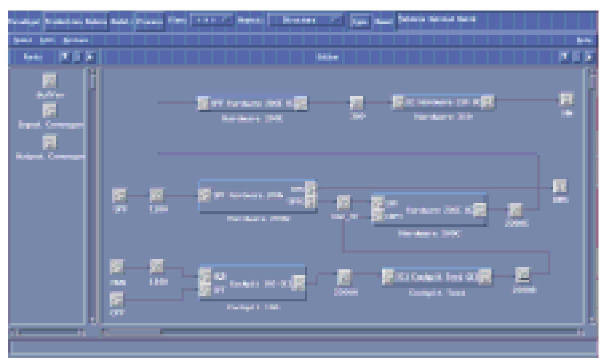

Figure 1: Model for "Vehicle Initial Build"

However, they are not described here for the sake of brevity.

5. Data Acquisition, Storage and Rerieval

Once the data has been modeled, it needs to be collected in real-time. The data acquisition is done using the traditional PM&C (Cimplicity). However, the use of models to guide data acquisition facilitates the implementation by providing a structured view of the data. We use the plant models to configure the interface to Cimplicity and the PLCs. As discussed in a later section, the use of models has aided considerably in bringing structure to the “chaos” of plant data

Time is an essential dimension in understanding the dynamics of production flow. There are some dynamics that are within the bounds of the current shift. Others involve multiple shifts, weeks, or months of history. There are “seasons” within the dynamics of production flow; statistically represented as a function of auto-correlation. To understand the dynamics of production flow, data collected in real-time needs to be stored for later retrieval and analysis. The stored data should contain detailed histories for every process and buffer in the plant. However, just storing raw data will render the data useless for any practical purposes, as has been the experience with traditional ISs at Saturn. The data should be structured according to the structure of the plant and the production flow. The use of plant models for providing the structure and format for storing the data alleviates this problem. Plant models are used to generate the underlying schemas for storing the data and to provide mechanisms for retrieval.

6. Visualization

The SSPF engineering process uses a visualization tool to make obvious the trends and variations in the production flow, thereby enabling the identification of problem areas and opportunities for improvement. As mentioned earlier, the traditional system for visualization was Cimplicity, which did not provide the functionality required for SSPF engineering process.

During 1993, a new concept of “production flow” was designed and implemented at Saturn. It involved selecting key measurements instead of production data for all processes and buffers. These key indicators were identified through experience. The main new indicators that received emphasis were buffers between processes. Over the last 3 years, these indicators have proven to be extremely useful for the operations leadership. This proved a principle that an engineering process used for productivity increase must eliminate excess data and provide only key indicators.

Beginning in late 1994, a manual evaluation process was initiated that involved calculation and posting of standalone capacity. This was intended as a key measurement of identifying bottlenecks for investment opportunities. The calculation of standalone capacity involves determining what the production rate of a process would be if there were no obstructions. Obstructions are:

- starving for material from upstream processes, or
- being blocked by processes downstream.

However, the traditional IS and engineering process employed at Saturn could support only the manual updating and posting of the standalone capacities once a month. In addition, the postings were not accessible to all Saturn team members and leaders, whose input is part of the business decisions at Saturn. The SSPF engineering process makes this, and all other real-time and historical data from across the site, available to all team members and leaders. In addition, standalone capacities, production rates, WIPs, blocking, starving, etc., are calculated and updated in real-time. By using this engineering process, improved decision making and responsiveness is expected.

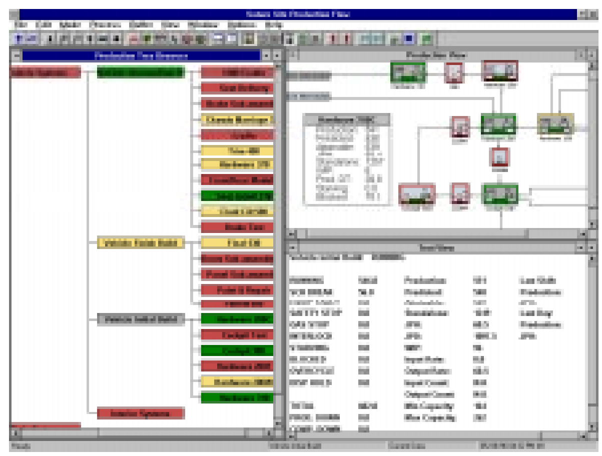

Figure 2: SSPF Visualization Tool GUI

The SSPF engineering process requires a visualization tool with many capabilities. Some of the requirements that relate to the Graphical User Interface (GUI) of such a tool are listed here:

- present a uniform view of the production flow across the site
- provide easy navigation through sections of the plant
- provide “understanding at a glance” of the status of production
- provide detailed and roll-up views of the plant
- provide current (real-time) as well as historical production flow visualization

There are many other requirements for the visualization tools that are not listed above for the sake of brevity. In addition, the visualization process is expected to evolve with time. In order to provide a visualization tool which presents a uniform view across the plant, evolves easily and changes as the plant changes, we used the models of the plant to configure the visualization. The use of models provides the structured, uniform view of the production flow which facilitates better visualization. Figure 2 shows the SSPF GUI with hierarchical navigation, drop down boxes and detailed textual report. On the left, the process hierarchy is shown, which allows the user to go to any section of the plant and examine it. On the right, the GUI layout for Vehicle Initial Build, as synthesized from the modes, and the textual report of production related data is shown. A drop down box for Hardware 200C (a sub-process of Vehicle Initial Build) is also shown, with summarized information about Hardware 200C.

7. Analysis and Decision Support Tools

Decision support tools help to design and verify interventions in plant operation. A decision support activity may include: data processing and visualization to recognize problems, bottleneck analysis for understanding the cause of the problem, and prediction to assess the impact of a planned intervention to resolve the problem. In this sense, decision support tools must help to define and execute integrated analyses. The components of these analyses may be elementary data processing, visualization, planning, prediction, etc.

Many tools and methodologies can be used for bottleneck identification and resolution, including analysis, simulation, data mining, etc. Traditionally, some tools and systems have been deployed at Saturn for performing analyses, simulations, etc. However, these systems are isolated from each other and many times the representations of the plant used by these systems differ significantly from each other. This makes it difficult to use the tools together, and to combine the results to facilitate better decision making.

SSPF provides an integrated problem-solving environment, which will allow Saturn personnel to use various tools together and make more informed business decisions. There are many different analyses that will be integrated with SSPF, for example, bottleneck identification, process simulation, what-if analysis, capacity optimization, etc.

8. SSPF Deployment

SSPF was installed and has been operational since August, 1996. This initial version focuses on collection of data, making it available to users, and logging of data into a relational database. The most successful part of this initial release was providing necessary data for improving throughput. With the data being collected and logged it becomes practical to provide continuous and regular feedback to leadership. There was also a throughput task force established whose purpose was to achieve specific goals on the improvement of throughput. The primary measurement used by the task force for identifying areas (activation areas) requiring specific improvement programs and for measurement of progress was standalone capacity. The tool used for providing this measurement was SSPF. The requirement from the task force was to provide:

- a daily report to management that showed the previous day's performance.
- a weekly report concerning short term as wall as long term performance.
- a weekly report for each activation area showing long term trend.

Another benefit of using MIC for SSPF which was quickly realized was that of providing a structured and uniform view of the whole plant. As mentioned earlier, there are disparate practices in data acquisition (use of different engineering units, measuring different quantities, etc.) in different sections of the plant. This presents a considerable challenge for an IS. In SSPF, this problem was addressed by modeling the different data acquisition practices along with the plant models and using these models to configure the data acquisition system. In this way, SSPF brought together the disparate practices and framed the available data into a structure which allows the user to look at the production flow in a uniform manner across the plant. This has led to identification of areas where the data collection itself needs to be improved.

During the initial phase of SSPF deployment, there has been a cycle of modeling, generation of run-time system and integration. This process has been facilitated considerably by the use of MIC and has had quick turn around time for any needed upgrades in the models or the run-time system.

Advanced features for which SSPF is expected to have the greatest utility are under development, for example, bottleneck identification, deterministic analysis, statistical analysis, process simulation, and decision support. With a solid platform of data collection, retention, and handling, we are positioned to proceed with these functions.

9. Conclusion

In this paper we presented a model-integrated solution for an engineering process to improve productivity and throughput at a discrete manufacturing plant. MIC technology provides a conceptually strong solution framework for the SSPF application. Considering the diversity of requirements and data sources, complexity of logic would be high with a traditional code solution. The solution environment is quite chaotic. Traditional code solutions would require a significant effort in placing order to these data sources. This structure can readily be expected in a virtual view of the manufacturing plant floor through models. Diverse services are required for the application such as PM&C, process simulation, statistical analysis packages, and other data manipulation tools. Integration of these tools into a common problem-solving environment is readily achieved through the use of model integrated computing. The most fundamental business problem involved in the SSPF application concerns identification of bottlenecks and the ultimate prediction of the results of elimination of the bottleneck, specifically total throughput from an action or set of actions. The expectations is that through application of models, the creation of algorithms that emulate soft rules and the seamless integration of third party analytical tools, decision making can be supported in a cost effective manner.

10. References

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