REAL-TIME ENTERPRISE OPTIMIZATION IN THE POLYMER MANUFACTURING INDUSTRY

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Abstract

A polymer manufacturer needs to be able to make profitable, proactive decisions about manufacturing that supports the business goals and incorporates the demands of the customer. To achieve this, the company must tie business and manufacturing processes together to make the best decisions. Orders and forecasts must be integrated with planning, scheduling, and plant operations. Existing technology solutions have created operational silos, which has led to a variety of point solutions that fail to link the business goals to the plant process. The key issues in the optimization the production operation are the decomposition of decision-making tasks, the modeling of options for these tasks, and the communication among the tasks. The decomposition establishes the scope for the decisions to be addressed for the planning, scheduling, and control tasks. Each decision-making task uses a model of the underlying closed-loop process to reflect the options and constraints on the decisions. In polymer production, the use of a static transition matrix neglects the options of choosing different paths for the transition. In order to leverage the flexibility in the plant operation, the decision-making tasks must have a model that describes the available options and tradeoffs for the process operation. The result is an integrated enterprise optimization solution for polymer manufacturing that allows the enterprise to adapt to different business contexts and opportunities.

Keywords

Coordinated Decision Making, , Planning, Scheduling, Control, Transitions, Polymer Manufacturing

Introduction

Polymer manufacturers use multiple, high-capacity continuous processes that are capable of producing many different product grades. The goal of the polymer enterprise is to maximize profits by producing and delivering quality products. The efficient, economic operation of the enterprise involves the coordination of many different decisions, and the optimization of these decisions defines the enterprise optimization problem.

This paper describes the issues involved in enterprise optimization with particular focus on the polymer industry. The key points are the decomposition of the problem into distributed decision-making processes and the integration of these processes such that their coordinated execution leads to the optimal performance of the enterprise.

Enterprise Optimization

From a holistic point of view, enterprise optimization deals with the optimization of all of the decisions that need to be made throughout the enterprise. These decisions range in scope from decisions about contracts and capital expenditures to decisions about plant floor operations and range in time scale from those made over years (long-term) to those made over seconds (short term).

The operation of an enterprise involves a very large number of decisions that have complex interactions. Thus, the enterprise optimization leads to a large, complex problem. This can be envisioned as an extremely large optimization problem where the all of the decisions and complex interactions are modeled and optimized simultaneously. Enterprise optimization is handled by decomposing the problem into smaller decision-making processes, distributing these processes throughout the enterprise, and coordinating the execution of these processes.

Enterprise Decomposition

The key to managing all of the decisions is the decomposition of the problem into smaller decision-making processes. This leads to a network of decision-making processes that are distributed throughout the enterprise. The individual decision-making tasks have their own objectives, but their operation in concert contributes to the overall goals of the enterprise.

There are several reasons for the decomposition. First, it makes the solution of the problem more tractable. Instead of a very large, complex problem, there are many smaller, simpler problems to solve. Another reason is that the decomposition provides robustness. Any failure in individual decision-making processes does not cause a failure in the entire enterprise. Finally, the decomposition defines the ownership and accountability for the particular decision making tasks. This provides the business context for the individual decision-making tasks.

The main challenge is determining how to decompose the system. The general approach is to include highly interacting decisions within the same decision-making process while maintaining a reasonable problem size. Two common bases for decomposition are time scale and scope. Decomposition based on scope is a common problem in distributed control systems where individual units are controlled independently. Decomposition based on time scale is handled by analyzing the characteristic time for the decisions that are involved.

The current practice is to decompose the enterprise based on both time and scope into the decision-making systems of planning, scheduling, and control. This leads to the common, hierarchical structure where higher-level decision-making processes pass directive and constraint information to lower-level processes and status and state information flows from lower-level processes to higher-level ones.

The problem is that these systems have evolved independently using different information, different models, different solution techniques, and a different set of users. It has led to isolated point solutions with poor communication and an inability to adapt to changing context and situations.

The current marketplace is highly competitive with more demanding customers. Demands change frequently as new orders are processed and forecasts are recomputed. This places more emphasis on rapid response to demands, smaller inventories, and reductions in working capital. This leads to increased interactions among the business processes, smaller lead-times for manufacturing, and less tolerance in the operations. Thus, the decision-making processes in the enterprise must be integrated together.

One of the problems with the current approach is that there is a fixed decomposition for the decision-making processes. In fact, many businesses have structured their business processes around this decomposition. The decomposition is still necessary, but it needs to reflect the current economic conditions, technology, and business structure. The fundamental feature must be the ability for the enterprise to adapt as these change.

The advances that have been made in information technology, computational technology, and solution techniques make it possible to reevaluate the decomposition of the enterprise. However, the barriers in implementing a new decomposition are not only technical, but also involve modifying human and organizational behavior (Shobrys and White, 2000).

The proposed solution is to deliver an enterprise optimization architecture that allows for the flexible decomposition of the enterprise and provides the communication infrastructure. The approach is to focus on the decision-making process and its key attributes rather than the individual applications. This decision-making process is a feedback loop shown in Figure 1. The decision generator uses context and measurement information to determine the decisions that should be applied to the system. This structure is applicable to the decision-making involved in planning, scheduling, and control systems. Each decision-making process can be configured with the appropriate model and optimization method. Therefore, the enterprise is not forced to map their problem into a predetermined formulation, which can limit the ability to achieve optimal operation.

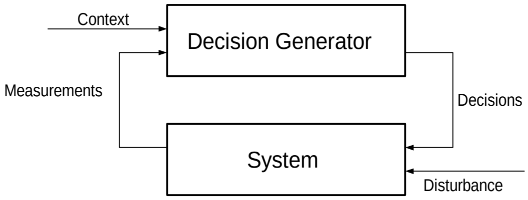

Figure 1. Decision-Making Process Schematic.

Integrated, Coordinated Decision-Making

The decomposition leads to a network of distributed decision-making processes that need to communicate with each other to link the business processes. An important feature of an enterprise optimization solution is an information technology (IT) infrastructure that provides the cross functional integration for effective decision making (McDonald, 1998). Since the software solutions for the individual tasks have been developed independently, integration is not a trivial task.

Since the decision-making processes involve complex, interacting decisions, they need to be coordinated. Although the information technology infrastructure provides the means for an arbitrary decomposition and the ability to share information, it does not indicate the interrelationships nor what information to pass between the processes to ensure consistent decisions. While much research has focused on the individual decision-making tasks, little work has focused on their coordination.

Coordinated decision-making requires that a decision-making process understand the subordinate process. In the hierarchical decomposition, one decision-making process is actually controlling one or more other decision-making processes. The higher-level decision-making process determines constraint and objective information that is used by the lower-level process during its decision-making. The key point is that the model used in the higher-level decision-making is a model of the closed-loop process in the lower-level application. This is described in Figure 2 where the higher-level system (e.g. a scheduler) uses a model of the lower-level system (B) for its decision making. The lower-level system (e.g. a control system) uses a model of its subordinate process (A).

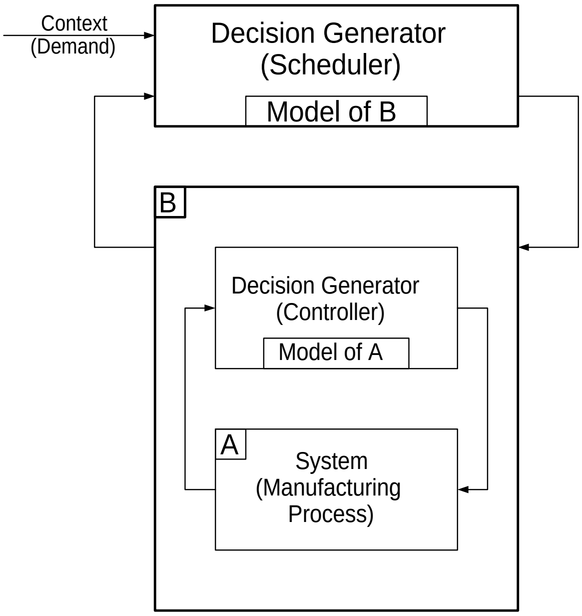

Figure 2. Integrated/Coordinated Decision-Making Processes (Scheduling and Control).

In the polymer enterprise, continuous manufacturing lines produce multiple products by performing transitions from one grade to another. These transitions involve a period of time where the process is generating material that does not meet any product specifications (off-spec). The time and cost associated with a transition is a function of the product sequence and the transition paths. Large jumps in the grade level can take a lot of time and be very costly.

The operation of the manufacturing system involves the competition between the manufacturing goals and the sales and marketing goals. The goals of sales and marketing are to meet customer demands, capture market share, and achieve forecast objectives. This leads to the type of schedule shown in Figure 1 (top), which is characterized by high transition costs, low inventory costs, and product delivery exactly on due dates. The goals of the manufacturing system are stable, safe plant operation, consistent product quality and minimal operating costs. This leads to the type of schedule shown in Figure 2 (bottom), which is characterized by low transition costs, high inventory costs, and penalties for late delivery.

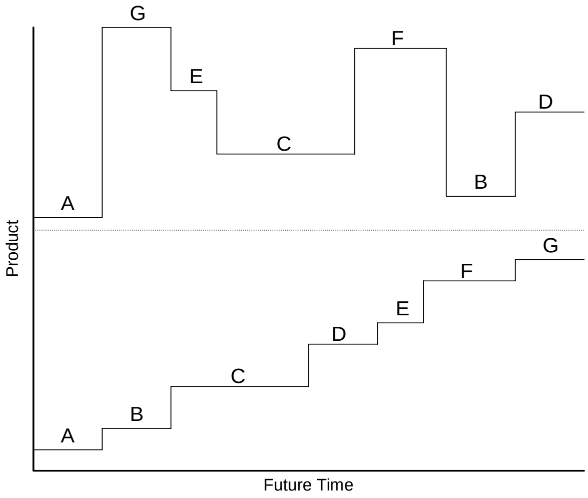

Figure 3. Sales and Marketing-Driven Schedule (top) and Manufacturing-driven Schedule (bottom).

In both cases there is a failure to model the different options for the transitions. In the sales driven case the transition effects are not included, and in the manufacturing case, only one transition path is permitted. The reality is that there are many different transition options. From one grade to another, different transition paths are possible, and the shape of the path determines the cost and time associated with the transition. Transitions can even occur by shutting down a line and restarting at the new grade level. Takeda and Ray (1999) and McAuley and MacGregor (1992) have examined optimal grade transition and have outlined the tradeoffs involved.

In most scheduling solutions, the transition is modeled using a transition matrix for all the possible grade transitions (Sahinidis and Grossmann, 1991 and Pinto and Grossmann, 1994). Each matrix element represents a fixed cost and time associated with a predetermined transition path from one grade to another. Thus, the scheduler does not have the option to choose the transition path.

The scheduling decision-making needs to have information about the transition options so that it can balance the sales and manufacturing goals. It needs to have a trade-off model of the closed-loop control system for the different transition paths. Instead of using a static matrix, it uses a model that allows for different transition paths to be used. The scheduler then has the ability to trade off the manufacturing, transition, storage, and late delivery costs and can choose the best path for each transition.

This approach requires an abstract relationship among the transition time, cost, and process yields. Bhatia and Biegler (1996) have examined the consideration of lower-level operational issues during the scheduling task for batch scheduling and Alle and Pinto (2002) have for continuous, cyclic scheduling. They indicated the complex tradeoffs among the scheduling options: production rates, yields, operating costs, and unit availability. The concept of bringing the lower-level operational issues into the scheduling problem raises the issues of what options are available to the scheduler what is being modeled in the scheduling problem.

Rolling Horizon Decision Making

The decision-making processes associated with the enterprise operations are dynamic systems. Dynamic optimization is required to generate the time series of actions that are used to control the outcomes of the system.

Planning and scheduling decision-making processes are usually handled by generating a static plan and then following it as closely as possible over the horizon. The problem is that there is usually some variability in both the external market and internal process. The demand may change as new orders are processed and forecasts are recomputed, and the manufacturing system may not operate as expected due to disruptions in the process.

This dynamic optimization problem can be addressed using methods for process control. Perea-Lopez, et al. (2000) examined the application of classical control theory for supply chains and developed control laws for their operation. Vargas-Villamil and Rivera (2000 and 2001) applied model predictive control techniques to planning and scheduling tasks. The advantage is that this approach draws on the knowledge available from control theory.

The static approach can be viewed as a model predictive control strategy where there is no feedback and no rolling horizon. If the process operation deviates significantly from the plan, a reschedule can be performed to determine how to recover. A more systematic way of addressing the problem is to use the rolling horizon strategy used in model predictive control applications. A schedule is generated, but only the first control action is implemented, and a new schedule is generated at each time step. Any changes such as a deviation from expected operation (disturbance) or change in the context (set-point) will be addressed be generating a new schedule.

The repeated generation of new schedules may require that constraints be imposed to keep a new schedule from deviating significantly from the previous one. This implies that the state of the scheduling system (the current schedule) must be monitored as well as the state of the process (current operating conditions).

Conclusions

Enterprise optimization requires coordinated, distributed decision-making. The system needs to be structured such that the optimization of the individual decision-making blocks leads to the optimization of the overall enterprise. This requires an appropriate decomposition, and integrated framework, coordination, better modeling, and better information usage.

The changing economy requires businesses to be flexible and responsive to market dynamics. The enterprise optimization solutions must mirror this environment. The structure and roles of the decision-making processes in an enterprise are not predefined structure and are constantly changing. New, dynamic and flexible ways of decomposing the enterprise lead to decision-making networks with better connections and better communication among the different decision-making components. This enables the enterprise to be more flexible and agile in responding to changing market and customer needs.

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