CONCURRENT CAPACITY PLANNING: ALIGNING SUPPLY CHAIN AND BUSINESS CAPTURE STRATEGIES THROUGH RISK-BASED PLANNING AND SCHEDULING (RPS)

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ABSTRACT

Lockheed Martin Aeronautics was awarded a contract for final assembly of the F-35 fighter aircraft. The completed aircraft is comprised of four main sections: forward fuselage, center fuselage, wing, and aft and empennage. These sections, along with supporting subsystems, are produced across a global supply chain. The supply chain is unique in that partner nations act as both consumers (taking orders) as wells as suppliers (providing capacity). This dual relationship requires that Lockheed Martin carefully manage industrial participation in a way that balances cumulative production forecasts with incremental changes in capacity.

An enterprise production model has been created to support analyses regarding the impact of future business partnerships. This model provides strategic guidance when planning for perturbations in production capacity. The model was created using a risk-based planning and scheduling software tool from Simio. Simio approaches risk-based planning and scheduling with simulation, hierarchical modeling, and abstracting component details at the enterprise level.

1 INTRODUCTION

The contract for production of the F-35 aircraft was awarded in October of 2001. The U.S. Department of Defense (DoD) selected Lockheed Martin as prime contractor for F-35 production, with plans to build a total of 465 aircraft during Systems Design and Development (SDD). Continuing after the SDD phase, the program anticipates production volume to reach over 2,500 aircraft at a programmed cost of over $200 billion (DoD 2003).

The F-35 program was initially conceived as an international acquisition program. The program is unprecedented in the level of investment it has attracted from partner countries. Although the U.S. is the primary customer and financial backer of the F-35 program, eight partner countries have invested $4.5 billion in the program to date, 18% of total SDD funding. Furthermore, there is a significant opportunity for suppliers to win work on the program – sources for many important subsystems are yet to be selected. Many of these contracts will be filled through purchasing countries (DoD 2003).

The acquisition strategy behind the F-35 program was developed with the intent to partner with governments who would likely become users of the fighter aircraft. These partnerships have added complexity to the F-35 supply chain. Because partnering countries act as both consumers and suppliers to the F-35 program, there is a dual buyer-supplier relationship that must be managed. This dual relationship requires that cumulative production forecasts be balanced with incremental changes in capacity. Management of the buyer-supplier relationship is further complicated by the rate at which production increases. Over the next seven years, acquisition plans call for a dramatic increase in throughput until a new fighter is delivered every working day, or about 240 jets in a year (Gertler 2009).

The buyer-supplier relationship results from consumer influence on the outcome of the buyer-seller contract. Although this relationship adds complexity to the contract under execution, advantages exist for both sides of the contract. For the buyer, securing subcontract guarantees and work-share opportunities offset acquisitions costs. Furthermore, such opportunities increase the likelihood of future business as the buyer retains technological capabilities that would otherwise be lost. For the supplier, this relationship is associated with greater self-support, directing revenue, and greater supplier advocacy.

The global scale of the F35 supply chain, along with the need to manage incremental changes in capacity, presents a significant management challenge. Lockheed Martin has developed an enterprise production model to simulate the effects of its buyer-supplier relationships. This enterprise model provides a management tool to balance the impact of strategic business opportunities with operational decisions during the ramp up of F-35 production. The result of this model is increased alignment between supply chain strategies and business pursuits. Risk-based simulation runs help discover how best to balance cumulative production forecasts with incremental changes in supplier capacity.

This paper presents the construction of a risk-based enterprise production simulation to manage the buyer-supplier relationship for the F-35 program. This risk-based planning and scheduling simulation is performed using Simio, an object-oriented simulation software tool. The approach to risk-based planning and scheduling taken by Simio supports hierarchical modeling, abstracting component details and delivery schedule risk at the enterprise level as well as detail individual plane order level. This offers the opportunity to integrate the business development forecast with the supply chain to predict the most effective contract terms for all members considering risk and uncertainty.

2 ALIGNING SUPPLY CHAIN AND BUSINESS STRATEGY

Aligning supply chain and business development strategies has been a topic of research in supply chain management (Cavinato 2002; SCOR 2010; Mukhtar and Shaharoun 2002). The objective of aligning supply chain and business development strategies is to increase the overall value of the business. This is achieved when both functions provide a mutually supportive role: supply chain supports business growth while development leverages supply chain efficiencies.

The buyer-supplier relationship adds complexity by directly coupling the two strategies. In the buyer-supplier environment, the supply chain strategy and business development strategy are mutually dependent and must be aligned to be successful. Managing either one alone leads to suboptimal results.

Traditional supply chain management focuses on the distribution channel from the supplier to the consumer where the objective is to operate this channel as efficiently as possible. The traditional supply chain management paradigm does not consider complex environments in which the buyer and supplier are the same entity. In such environments, focusing on supply chain optimization alone is done at the risk of precluding future business sales.

Traditional business capture focuses on winning future business. The capture planning process converts market opportunities to sales through an internal development plan. Traditional capture planning is customer focused. As a result, it becomes increasingly difficult to assure capture plans are aligned within the business. By focusing on the capture planning process alone, the business runs the risk of over-committing resources and thereby increasing business costs.

Successfully managing the buyer-supplier relationship requires a balanced approach to managing both supply chain and business capture functions. One function cannot be optimized at the expense of the other. An enterprise perspective combines multiple functions, providing a balanced view of the problem space. In the case of the dual buyer-supplier relationship, an enterprise perspective is used to align the activities from both supply chain and business capture.

While traditional supply chain management has been treated as an execution detail after business capture, an enterprise modeling approach integrates supply chain strategy within the business capture function. Elevating supply chain performance within an enterprise model provides shaping for supply chain decisions and assures greater alignment for the supply chain strategy.

3 ENTERPRISE PRODUCTION AND RISK-BASED SIMULATION

The use of risk-based modeling and simulation in supply chain management is particularly useful when seeking to manage complex interactions such as those found in the buyer-supplier relationship. Moreover, by viewing the enterprise as a set of concurrent sub-models, it becomes possible to manage a complex business relationship, such as the balancing sales growth with operational execution.

The existence of various supply chain simulation studies (Hieta 1998; Bagchi et al. 1998; Ingalls and Kasales 1999; Archibald et al. 1999; van der Vorst et al. 2000) are evidence of the value that simulation provides to supply chain management. Simulation is valuable when exploring possible outcomes in a virtual environment. Simulation permits the evaluation of an idea or concept of operations prior to execution. In the practical application of this concept, the development of the simulation model for supply chain management has become a necessity (Chang and Harris 2007).

Previous research has attempted to categorize the use of simulation according to application (Oren 2005; Banks 2005; Survey 2003; Rizzoli 2009). A total of 22 application environments were cited by Abu-Taieh and El Sheikh (2009). From this list of application environments, Supply Chain Management, Finance, Process Design, Manufacturing, and Decision/Risk Analysis are all included. However, these application environments are treated independently -- the enterprise is not considered as a whole.

Enterprise modeling combines multiple, concurrent sub-models within a larger framework. The objective of enterprise modeling is to identify areas of alignment across the enterprise. This leads to the discovery of system efficiencies, not localized optimization in one business function at the expense of another.

Concurrent capacity modeling integrates capacity-related models from across the enterprise. Models are built and run in concurrent fashion, iterating over the solution space. This approach helps to identify tradeoffs in production capacity as they impact the enterprise. As constraints are identified in one model, related sensitivities are discovered in neighboring models. Concurrent capacity modeling preliminary shaping for the supply chain decisions assures greater alignment for the supply strategy.

To build an enterprise production simulation environment, it is necessary to address both the breadth (integration) as well as well as the fidelity (hierarchy) of models. Model integration describes the act of exchanging analysis variables across multiple, independent models. Model hierarchy describes the act of calling sub-models for more detailed information.

3.1 Model Hierarchies

Hierarchies add structure to related models at different levels of fidelity. At the top of the hierarchy are abstract models; these are low fidelity yet more comprehensive. They provide a strategic outlook over the supply chain. At the bottom of the hierarchy are the high fidelity models. These models provide much more operational detail and provide a foundation for the analyses completed at the top of the model hierarchy.

Hierarchy provides the framework for concurrent capacity planning across the enterprise business model. Hierarchy describes the act of sub-classing objects to define more specific behaviors at a tighter resolution. Hierarchy allows existing objects to be modified with additional functionality. Therefore, designing hierarchical systems requires that the modeler think from general to specific.

Shewchuck and Chang (1991) propose modeling hierarchies in the form of base levels of classes that are common to all modeling and simulation. Next, they suggest building object libraries core to your line of business, etc. Afterword, application specific classes are made to support a model.

An appropriately structured hierarchy not only supports model concurrency, it also improves model reuse. An enterprise model provides abstraction across a dynamic and complex environment. It is possible that a higher level simulation be created by combining the relevant, lower-level simulations (Might). By implementing model hierarchies, changes are isolated to their relative area of impact.

3.2 Object-Oriented Modeling

Traditional simulation models are classified as being event-oriented (tasks), process-oriented (time-dependent behaviors), or application specific (data driven) (Shewchuck and Chang 1991). More recently, the modeling flexibility and scalability of object-oriented software has influenced discrete event modeling/simulation.

Under this paradigm, the modeler is able to create, manipulate, and destroy objects in much the same way we think of a physical system. Objects are designed around the way you would naturally encounter and use those objects. Internal to the class is a set of methods, variables, and interfaces that allow the modeler to use the class, interacting in a natural way. The internal mechanics are abstracted away from the user, providing the functionality desired.

The shift in emphasis from data manipulation to object interactions produces a more natural framework for discrete-event simulation. This paradigm extends the modeling approach from building a single, analysis-specific model to building a library of potential model components. The power of the model library is that it enables model reuse when exploring what-if scenarios. Thus, the speed and breadth of search is greatly increased. For example, the modeler may construct a library of components: transporters, belts, combiners, etc.

3.3 Risk-based Simulation Tools

When selecting a modeling tool, it becomes highly relevant that the tool support the modeling capabilities required by the application environment (Abu-Taieh and El Sheikh 2009). The concern in enterprise modeling that most characterizes tool requirements is the need to support model hierarchy. This need translates to scalability across the enterprise problem space. The model must scale from the specifics to abstract, from detailed station-level information to multi-product strategy.

Simio is a ***sim***ulation modeling framework based on ***i***ntelligent ***o***bjects. The intelligent objects are built by modelers and then may be reused across multiple modeling projects. Although Simio supports multiple modeling views, it was built around the object-oriented paradigm. As such, the activity of building an intelligent object in Simio is identical to the activity of building a model. This concept is referred to as the equivalence principle and is central to the design of Simio. A model is, by definition, an object that can be instantiated into another model. (Pegden 2008).

Simio also has the unique ability to support the enterprise production simulation environment for shaping supply chain and business development strategies with risk-based planning and scheduling. Although Simio is focused on discrete event simulation, the inclusion of cost data/models in a concurrent modeling environment, makes it possible to shape the two strategies simultaneously. Moreover, Simio models are built on a hierarchical paradigm, supporting variable fidelity and breadth of the enterprise model with risk analysis.

4 FORMULATING THE F-35 ENTERPRISE PRODUCTION SIMULATION

An enterprise production simulation was created for the F-35 program. The simulation was based on concurrent capacity models for both supply chain business capture. These models were then run using Simio, where both financial data and capacity plans were brought into alignment.

The model was built on a number of assumptions which characterize the uniqueness of the program. They are stated here:

1. Deterministic demand: a fixed order schedule is defined within a scenario.
2. Stochastic supply: variation exists within planned capacity.
3. Product variants: variant specific parts are tracked and managed.
4. Learning curve: completion time is reduced according to learning curves.
5. Dynamic changes to network: suppliers come online/offline mid-run.
6. Solid-chain production system: rate-based and pulse-based stations operate without buffers.

The above assumptions drove the overall development approach for the enterprise model. The models were constructed to support strategic decisions and not detailed execution. As such, many of the supplier nodes were modeled as single rate-stations, defined per contractual agreement. Additional detail was added for internal production facilities and then replicated where duplicate facilities were located.

The need for a flexible model to be used throughout the extended program life posed a challenging design problem. To address this, operations performance and cost models were managed independently and integrated at execution time. This separation provided greater flexibility.

The supply chain model required operations data describing the capacity and variation from operations. These statistics include values for crew sizes, work schedules, efficiency rates, etc. The business capture model required financial data describing the capital outlay required to finance operations. These statistics include the variable and fixed cost for facilities, tooling, and earnings schedules. To configure the Simio model, operation and financial data were imported from external Excel workbooks into Simio data tables and then referenced by individual modeling components (see Figure 1).

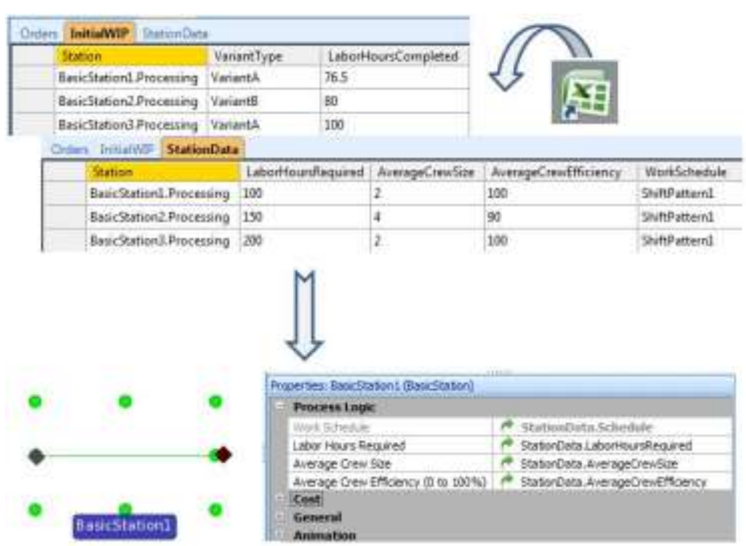

Figure 1: Model Configuration Using Operation & Financial Data

The model was organized hierarchically. First, an F-35 object library was created. This initial investment in the design of a custom library allowed for the rapid construction of highly detailed models. The custom library included stations for 'basic station' and 'assembly station' tasks. The library also included routing nodes to handle the mixed-model problem discussed earlier. These nodes were used to direct variant subassemblies to the correct assembly station when presented with the multiple, duplicate stations. Lastly, the library contained graphics used to represent the 3D shape and coloring for each of the three F-35 variants.

The basic object library was used for constructing more detailed models using an object-oriented modeling approach (see Figure 2). Model scenarios were crafted around specific tasks and geography. These models were imported into larger models including the final assembly of the F-35. Lastly, one enterprise model was formed by importing a mixture of sub-models. The ability to both create a custom library for building the initial set of models, as well as the ability to combine these models hierarchically was critical to the success of the enterprise modeling effort.

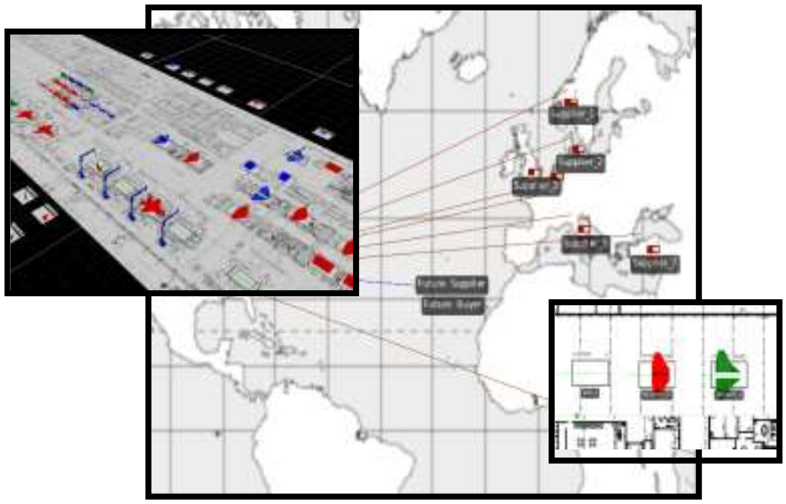

Figure 2: Object-Oriented Model of Processing Stations and Workflow

The enterprise production model was built up from multiple sub-models, decomposed according to plane section: forward fuselage, center fuselage, wing, and aft and empennage. Furthermore, scenario specific variants of these sub-models were created using as part of an enterprise object library. This use of model hierarchy allowed model objects to be organized for a variety of business scenarios. Figure 2 depicts simulation objects from international suppliers. These objects are then combined within a single enterprise model.

5 EVALUATING SIMULATION OUTPUTS

The enterprise simulation yields capacity and timing information regarding how the overall enterprise should scale over time to support production contracts. These results include the effect of adding demand from a supplier that will also add incremental capacity. The enterprise simulation provides an understanding of the tradeoffs used to shape the contract rather than to accept and execute business based on intuition only.

Sensitivity analysis is used to understand how work is best managed for a potential buyer-supplier. As constraints are discovered in one sub-model, sensitivities are explored through altering other, concurrent sub-models. A 3D sensitivity plot is produced to understand the sensitivities between cost, schedule, and risk for a given scenario. Figure 3 depicts this plot, highlighting cost (capacity), schedule (variation), and risk (confidence) on their respective axes.

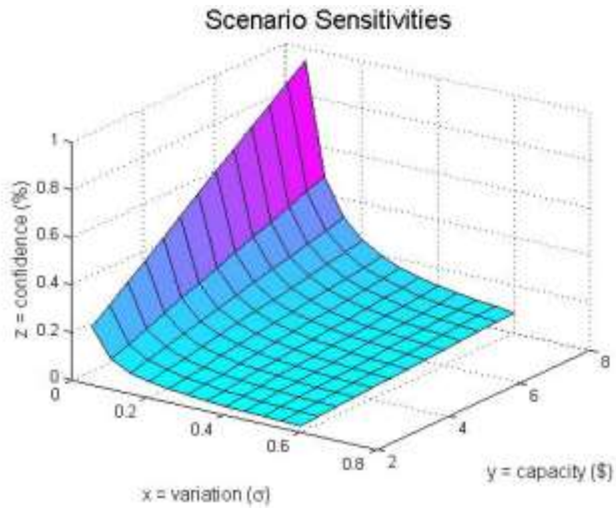

Figure 3: Sensitivity plot illustrating capacity, variation, and risk trades

Sensitivity analysis, when applied to a concurrent capacity planning scenario, provides information for decision making. "Confidence" is generated from the stochastic properties of the simulation. An understanding of the assumed risk is had by running a scenario with high and low value estimates. "Variation" refers to the degree of uncertainty in value estimates. Variation refers to predictions in financial data as well as production data. "Capacity" refers to metrics defining execution capability. These metrics may resolved into dollars regardless of the business function, whether it by fixed costs of new machinery or variable costs of labor.

Concurrent sub-models are perturbed by changing parameter values. As values change, the effect of any one model may be observed as it interacts with other sub-models to generate a global picture of cost, schedule, and risk.

Sensitivity studies provide an increased understanding when faced with strategic decisions. By understanding these sensitivities, the performance of the supply chain is brought into balance with the capture of new business. Once alignment has been achieved, it is possible to move beyond the shaping stage and consider implementation details.

6 CONCLUSIONS

Traditionally, supply chain management has been treated as a management philosophy which seeks to support the business by increasing the operations efficiency and effectiveness. However, as business is forced to operate in more complex settings, the need to align operations with business strategy is emphasized. The need for this alignment has been observed in the case of the F-35 program with a dual buyer-supplier relationship that tightly couples supply chain and business decisions to mitigate delivery schedule risk.

The influence of the buyer-supplier relationship exists beyond the F-35 acquisition program. Broader forms of this relationship may be observed within parent companies, trade associations, user consortia, standards bodies, marketing groups; any time a potential buyer leverages his position to participate in a portion of the production activity. In such environments delivery schedule risk is heightened and an enterprise perspective is required to shape future contracts.

Enterprise-level risk-based simulation was used to better understand the business and operations interactions for the F-35 program. A model was built using Simio in a hierarchical manner, allowing risk-based concurrent analysis of both operational and business propositions. The use of risk-based concurrent capacity models has helped to align the business capture function with the production operations function, providing a valuable management tool for understanding the impact of strategic business decisions.

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