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Analyzing the Effectiveness of Availability Management Process

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Abstract:

Availability management is a major factor for successful supply chain management since it influences key supply chain performance metrics such as customer service level and inventory. The availability management process involves generating availability outlook, scheduling customer orders against the availability outlook, and fulfilling the orders. The process is also associated with many uncertainties such as customer demand, customer preference of product configuration, changes in supply constraints and various supply chain policies, which also affect the supply chain performances. As e-Commerce is becoming a major part of business transaction it is much easier for customers to compare availability and services from many different sellers. Therefore, it is important for sellers to process customer orders in real-time, promise ship dates, fulfill the orders as promised, and to have availability of resources to be able to promise customers desirable ship dates. In today's competitive and dynamic business environment, companies need to continually evaluate the effectiveness of availability management process and supporting IT system, and look for ways to transform the process to achieve a better customer services and profitability. In order to do that there is a need for an easy-to-use modeling tool that can accurately assess the effectiveness of existing availability management process, evaluate the impact of

potential changes to the process and identify opportunities for improvement. In this paper, we describe an availability management simulation tool that was developed at IBM to support the continuous effort to improve availability management process. The simulation model has become a critical tool in making strategic business decisions that impacts customer services and profitability in IBM.

1. Introduction

Being able to promise customers the desirable delivery date and fulfilling the orders as promised are an important aspects of customer services. The recent surge and wide-spread use of e-Commerce mean that shoppers can now more than ever easily assess and compare customer service quality in addition to quality of goods and price among different vendors. This creates a very competitive business environment, thus making customer service a critical factor for success and survival of many companies. Competitive pressures are forcing companies to constantly look for ways to improve customer services by evaluating and redesigning supply chain processes. Availability Management Process (AMP) is a key process that impacts the customer service since it determines customer promised ship (or delivery) dates, the accuracy of the promised ship date, order scheduling delay and order fulfillment rate as well as inventory.

This work was motivated by supply chain processes of IBM's Computer Hardware businesses. In IBM, businesses are being managed as On-Demand business, where business strategies, policies and processes are continually evaluated and changed to meet increasingly demanding needs of customers. These changes are called "business transformations" in IBM. Various business transformation ideas are generated, evaluated and deployed to improve the effectiveness of the businesses especially in the area of supply chain. Availability Management Process (AMP) is one such area where transformation ideas are constantly evaluated and implemented. When a change in AMP is sought, for example a change in Available-to-Promise (ATP) generation method, an order scheduling policy or an order fulfillment policy, the impact of such change has to be accurately assessed before they are implemented because the changes are typically expensive and time consuming to implement in large enterprises as IBM. Other examples of changes in AMP can be moving from Make-to-Order (MTO) to Configured-to-Order (CTO) business, a change in demand classes, refresh rate of availability data base system and supplier flexibility etc. In addition, AMP is tightly associated with other exogenous changes in supply chain such as customer demand, customer preference of product configuration and changes in supply constraints. These exogenous changes in supply chain often force an enterprise to transform its availability management process. Changes in AMP typically require careful analyses to support the decision of whether or when to implement the changes. For example, it is necessary to determine how a change in order promising policy would affect the customer service improvement and inventory positions, and how expensive the supporting IT systems would be before the change is deployed in the business. Therefore, there is clearly a need for a tool that is readily available to simulate the affected supply chain and quantify the performance metrics fast and accurately before making costly investment. In this paper, we describe a supply chain simulation tool called AMST (Availability Management Simulation Tool) developed in IBM for the purpose. We also describe several case studies where AMST has been used successfully in evaluating availability management transformation opportunities in IBM.

The availability management involves *generating availability outlook*, *scheduling customer orders* against the availability outlook, and *fulfilling the orders. Generation of Availability Outlook* is a push-side of the availability management process, and it allocates availability into ATP (Available-to-Promise) quantities based on various product and demand characteristics and planning time periods. *Order Scheduling* is a pull-side of availability management process, and it matches the customer orders against the Availability Outlook, determines when customer order can be shipped, and communicate the promised ship date to customers. *Order fulfillment* is executing the shipment of the order at the time of promised ship date. Even if an order is scheduled for shipment for a certain date based on the outlook of availability, the resources that are required to ship the product on the promised ship date may not actually available when the ship date comes. A key role for effective availability management process is to coordinate and balance the push-side and pull-side of ATP.

Ball at al. (2004) gave an overview of the push-side (Availability Planning) and pull-side (Availability Promising) of ATP with examples from Toshiba, Dell and Maxtor Corporation. They stressed the importance of coordinating the push and pull-side of availability management for supply chain performance by making good use of available resources. Although ATP functions has been available in several commercial ERP and Supply Chain software such as SAP's APO, i2's Rhythm, Oracle's ATP Server and Manugistics' SCPO modules etc. for several years (see Ball et al. 2000 for details), those ATP tools are mostly fast search engines for availability database, and they schedule customer orders without any sophisticated quantitative methods. Research on the quantitative side of ATP is still at an early stage, and there are only a limited number of analytic models developed in supporting ATP.

For the push-side of ATP, Ervolina and Dietrich (2000) developed an optimization model as the resource allocation tool, and described how the model is used for a complex Configured-to-Order (CTO) environment of the IBM Server business. They also stress how the push-side (Availability Promising) and pull-side (Availability Planning) have to be work together for the overall availability management performance.

For the pull-side of ATP, Chen et al. (2002) developed a Mixed-Integer Programming (MIP) optimization model for a process where order promising and fulfillment are handled in a predefined batching interval. Their model determines the committed order quantity for customer orders that arrive with requested delivery dates by simultaneously considering material availability, production capacity as well as material compatibility constraints. They also studied how the batching interval affects supply chain performance with different degree of resource availability. Moses et al. (2004) also developed a model that computes optimal promised ship date considering not only availability but also other order-specific characteristics and existing commitments to the previous scheduled orders. Pan et al. (2004) also developed a heuristics-based order promising model but with E-commerce environment in mind. They modeled a process where customer orders arrive via Internet and as earliest possible shipment dates are computed in real-time and is promised to customers.

All the previous work described above deal with either push-side of ATP or pull-side of ATP, but not together. There have not been any quantitative tool that looks at both the push and pull-side simultaneously as well as other dynamic factors in supply chain, and evaluates the effectiveness of the overall availability management process. Some of the work described above use simulation experiments to measure the effectiveness of their solutions, but their simulation work was only capable of simulating very specific supply chain environment, focusing only one aspect of ATP process. In this paper, we describe an availability management simulation tool that evaluates how various components (*generating availability outlook*, *scheduling customer orders*, and *fulfilling the order*) impact the supply chain performance either by itself or in coordination with the others in various supply chain environment.

Discrete-event simulation has been around for many years in simulating Supply Chain Management (SCM) processes to evaluate its effectiveness. McClellan (1992) used simulation to study the effect of MPS method, variability of demand/supplier response on customer services, order cycle and inventory. Hieta (1998) analyzed the effect of alternative product structures, alternative inventory and production control methods on inventory and customer service performance. Bagchi et al. (1998) evaluated the design and operation of SCM using simulation and optimization, analyzed SCM issues such as site location, replenishment policies, manufacturing policies, transportation policies, stocking levels, lead time and customer services. Yee (2002) analyzed the impact of automobile model and option mix on primary supply chain performance such as customer wait time, condition mismatch and part usage. However, there hasn't been any simulation modeling work that analyzes both the pull and push-side of availability management process as well as the coordination between them.

The Availability Management Simulation Tool (AMST) is essential in supporting the continuous effort to improve availability management process. The tool is playing a critical role in evaluating various supply chain transformation initiatives and making strategic business decisions that impacts customer services and profitability in IBM. This paper also describes several realistic business transformation case studies which utilized the model in IBM.

The rest of paper is organized as follows. In section 2, we describe the availability management process based on our experience in IBM's hardware businesses. In section 3, we describe how the simulation model works and what it is capable of. In section 4, we describe several supply chain transformation case studies that we conducted with AMST, its impacts and results. Section 5 provides conclusion and remarks.

2. Availability Management Process

In IBM hardware businesses, the availability management consists of three main tasks: (1) *generating availability outlook*, (2) *scheduling customer orders* against the availability outlook, and (3) *fulfilling the orders.* There are two types of IBM's hardware supply chain environment that we studied in this work. The first one is HVEC (High Valued Easy Configured) business, which manufactures commodity-like hardware products such as personal computers. The second type is CCHW (Complex Configured Hardware) business, which manufactures more expensive, server-type computers.

For the HVEC business, customer orders typically arrive without any advance notice, requesting as early possible fulfillment of the orders usually in a few days. For this type of business, products consist of a few components and can be assembled rather fast to fulfill the customer orders.

For the CCHW business, on the other hand, customers place orders in advance of their actual needs, often a few months in advance. Typically, CCHW customers place orders as early as 3 months before the requested delivery (due) dates, and early delivery and payment are not allowed. For this environment, products usually consist of a hierarchy of complex components, and require a longer supply planning. Many buyers in this environment purchase products based on a careful financial planning, and they typically know when they want to receive the products and make payment. Customer orders in this environment are typically highly skewed toward the end of quarter, e.g, only a small portion of orders are placed in the first week of a quarter, and the orders gradual increase, and finally as much as 60-70% of orders are placed in the last 2 weeks of a quarter.

Generation of Availability Outlook, is a push-side of the availability management process, and it pre-allocates ATP quantities, and prepare searchable availability database for promising future customer orders. For HVEC business, the availability outlook is typically generated by daily buckets, and the availability planning horizon goes out to a few weeks in to the future. For CCHW business, the availability outlook is allocated by weekly buckets, and the availability is planned in much longer horizon, often a quarter (3 months) into the future. ATP quantity is called *Availability Outlook* for this reason. The availability outlook is typically generated based on product type, demand classes, supply classes, and outlook time buckets. The product type can be finished goods (FG) level for Make-to-Stock (MTS) business or components (Comp) level for Make-to-Order (MTO) or Configured-to-Order (CTO) business. Demand classes can be geographic sales locations, sales channels, customer priority, sensitivity to delivery dates, profitability and demand quantity. Supply classes can be degree of constraints and value of products. Outlook time buckets can be daily buckets or weekly buckets. Availability is pre-allocated into Availability Outlook bucket based on the dimension described above, and rolled-forward daily or weekly. The availability outlook is determined based on the availability of components, finished goods, WIP (Work-In-Process), MPS (master production schedule), supplier commitment, and production capacity/flexibility. When customer orders arrive, the availability outlook is searched in various ways according to scheduling polices to determine the ship (delivery) date that can be promised to customers.

Customer Order Scheduling is a pull-side of availability management, and it reacts to customer orders and determines ship date for the orders. For HVEC business, customers usually request the order to be shipped as early as possible, and they would also like to know when the order will be shipped. The CCHW customers usually request orders to be shipped (or delivered) in specified future dates. And they would like to know whether the requested due date can be met or how long is the delay if the due (requested) date can't be met. Customer orders arrive with various information such as product types, the demand classes, customer classes and due dates. The order scheduler then searches through the availability outlook database, and identifies the availability that meets the characteristics. The scheduling can also be done by an ATP engine that uses certain algorithm to optimize the scheduling considering various resources, policies and constraints. The scheduler then reserves specific availability against each order, and decrements the availability according to the purchase quantity of the order. The ship date of the order is determined from the time bucket where the availability reserved, and it is promised to customers. Depending on the business environment, various rules and policies are applied in this order scheduling process. Examples are first-come-first-served policy, customer priority-based scheduling, and revenue (or profit)-based scheduling etc. In a constraint environment, certain ceiling can also be imposed to make sure the products are strategically distributed to various demand classes.

Order fulfillment is executing the shipment of the product at the time of promised ship date. Even if an order is scheduled with a specific promised ship date based on the availability outlook, the availability (ATP quantity) may not actually exist when the ship date comes. There are several reasons why the orders cannot be fulfilled at the promised date. One such reason is the quality of availability outlook generation. In CTO environment, availability outlook is often generated based on finished goods availability, which is estimated based on supplier commitment on components and forecasted configuration of the finished goods. Since the component availability changes often and there is certain error in configuration forecast, the components that are required to assemble a certain finished good may not be available when it is time ship the product to customer. Another source for the fulfillment problem is due to IT system that supports the availability management process. The order scheduling is done based on the availability outlook data in an IT system, which is typically refreshed periodically since it is very expensive to update the database in real time. The availability information kept in the IT system (system availability) are not always synchronized with the actual availability (physical availability). Due to the potentially inaccurate view of the availability, unrealistic ship date can be promised to customer. Therefore, for certain customer orders the necessary ATP quantity may not be there when the promised ship date arrives, thus creating dissatisfied customers. The impact of IT on the fulfillment is discussed in detail in the section 4.3. Therefore, a key role for effective availability management process is to coordinate and balance the push-side and pull-side of ATP as well as IT resources.

3. Simulation Modeling of Availability Management

In this section, we describe the AMST (Availability Management Simulation Tool). The model simultaneously simulates the three components of availability management process, *generating availability outlook*, *scheduling customer orders* and *fulfilling the orders,* as well as the effect of other dynamics such as customer shopping traffic, uncertainty of order size, customer preferences of product features, demand forecast, inventory policies, sourcing policies, supply planning policies, manufacturing lead time etc. The simulation model provides important statistical information on promised ship date, accuracy of the ship dates determination, scheduling delay, fulfillment rate as well as inventory.

3.1. Modeling of Availability Outlook

Availability Outlook (also called Availability Quantity) is modeled by multi-dimensional data array which represents various attributes of availability such as product type, demand class, supply class and planning period. The product type can be either finished goods or components depending on whether the business is MTO or CTO. For a simple example, for a process where there are two attributes of availability (product type and time period), the availability outlook is represented by 2-dimensional data array shown as cylinders in the Figure 1. The availability outlook is time-dependent, e.g., there is availability for the current period (t=1), and there is availability quantity for future periods (t=2, 3, …) as more availability quantity is expected to exist through production or procurement in the future dates. The availability time periods can be daily buckets or weekly buckets depending on the business environment. For example, in the figure 1, the 3 of component 1 is available in the current day, and 5 more are expected to be available a day after, and 10 more are expected be available for day 3 and so on. The availability outlook is used in computing the ship date of customer requests and orders. The availability quantity changes as a result of many events in the business. In this work we models four main events that affect the availability, and they are explained below.

3.2. Simulation of Order Promising

The figure 1 shows an example of how the ship date calculation is simulated in this work. Customer orders or ATP requests arrive in certain stochastic interval, usually modeled as a Poisson process. Each order has one or more line items, and each line item has one or more quantities. The order quantities are modeled with probability distribution functions which are derived based on historic data. The line items and quantities are determined as the order is generated in the order generation event (details described in the next section). For each line item, certain components are selected as the building blocks of the product using a distribution function representing customer preference of component features. For example, in the Figure 1, the line item #3 of the order # 231, requires components 1, 3 and 4, one unit each. Different order scheduling policies can also be applied here in selecting specific components.

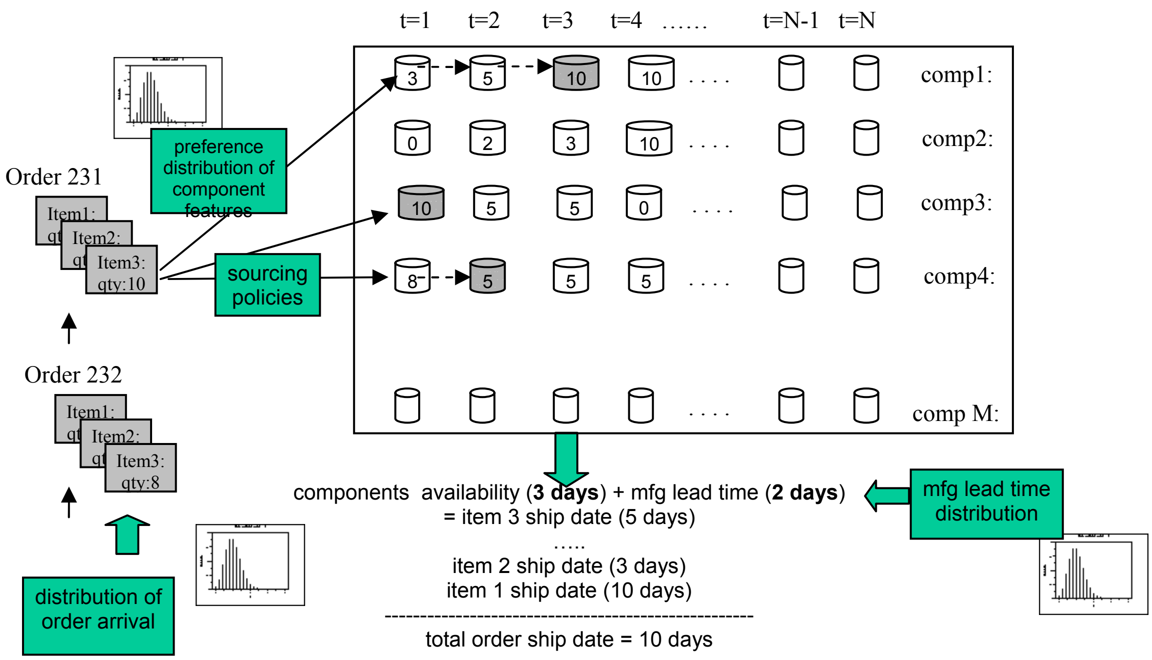

Figure 1: Simulation of Order Scheduling and Ship Date Calculation

for As Early As Possible Orders

For the orders that are requested to be fulfilled as *early as possible*, as described in earlier section as the HVEC business in IBM, the simulation model looks for specified quantity of a chosen component starting from the first time period to latter time periods until the availability of all the quantity is identified. In this example, the time periods (buckets) are in days. The component #1, the requested quantity of 10 is identified in the first 3 days; 3 in day 1 (t=1), 5 in day 2 (t=2), and 2 in day 3 (t=3). Therefore, for the line item#3, the required quantity of component 1 is available by the third day. Similar search is carried out for component #3, which is available on the first day, and for component #4, which is available by the second day. Therefore, the component availability of line item#3 of the order#231 is the 3rd day. In this example, let's assume that the availability calculated for the line item#1 is 8th day, and that of the line item#2 is 1st days. When all the components are available, the product is assembled or manufactured, which takes certain amount of time. The manufacturing lead time can a fixed number of days or it can be described with a distribution function. The lead time to ship date is then calculated by adding the manufacturing (assembly) lead time to the availability lead time. Assuming that the manufacturing lead time for this example is 2 days, the partial ship date for item#1 is 10th day, for item#2 is 3rd day, and for the item#3 is 5th day, if the customer is willing to receive partial shipments. And the total order ship date is 10th day from the date of order or request. Therefore, the lead time to ship date for the order #231 is 10 days for this example. When this order is scheduled, availability quantities are reserved (e.g, the availability is decremented) for the order. Typically, for each order, availability is reserved as late as possible so the availability in earlier time bucket can be used for generating favorable ship date for future orders. In this example as shown in the figure 1, quantity of 10 for component 1 is reserved in t=3, and quantity of 10 for component 3 is reserved in t=3. However, for component 4, quantity of 5 is reserved for t=1, and another 5 is reserved t=2 instead of quantity 8 being reserved of for t=1 and 2 for t=2 because having availability of 3 for t=1 is more valuable than t=2 for scheduling and fulfilling future orders. The scheduling logic can vary based on the business rules and policies.

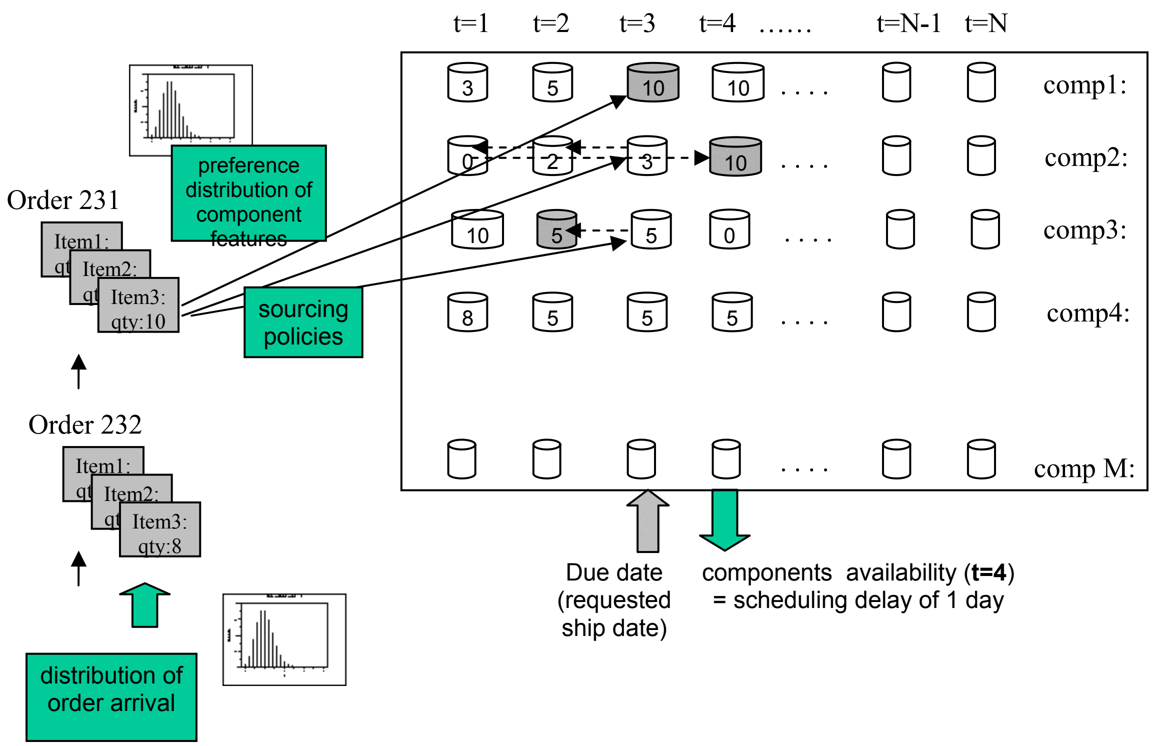

Figure 2: Simulation of Order Promising and Ship Date Calculation for Advance Orders

For the orders with *advance due date*, as described earlier as CCHW business of IBM, the simulation model looks for specified quantity of a chosen component starting from the time period of due date (requested ship date), searches backward into the earlier time periods, and then forward to later time periods until the availability of all quantity is identified as shown in the Figure 2. For this example, the item 3 of the order #231 requires for the quantity of 10 of component #1, #2 and #3. However, in this case the order comes with requested ship date of t=3, say 3 days from the time of order. For component #1, the simulation model finds the availability of 10 on t=3, and reserve the availability. For component 2, it finds quantity of 3 on t=3, then it searched backward to find 2 more quantity on t=2 and then move forward to find 5 more on t=4. But, in this case the simulation reserves availability quantity of 10 all on t=4 making availability quantity intact for t=2 and t=3 for future orders. For component 3, the simulation model finds availability of 5 on t=2 and t=3 each, and reserve them. In this case the overall availability date is t=4, a day after the due date. Therefore, the order scheduling delay here is 1 day.

3.3. Event Generation

In this work, the availability outlook changes as the result of four events; (1) demand event, (2) supply event (3) roll-forward event, and (4) data refresh event as shown in Figure 3. Each event changes the availability outlook; the demand event decrements the availability, the supply event increments the availability, the data refresh event refreshes the availability and the roll-forward event shifts the availability as explained in the next section. The events are generated independently using probability distribution functions or fixed intervals. The model can be easily extended to include more events depending on the supply chain environment being modeled.

Demand Event

The demand event is a pull-side of availability management, and it includes order scheduling and fulfillment. The demand event is triggered when customer orders are generated, and it decrements the availability outlook (quantity) when it schedules customer orders.

Customer orders are generated in certain stochastic interval, usually as a Poisson process. At this time of the order generation, each order is assigned with one or more attributes such as quantity, product type, demand class, supply class and due dates.

This assignment of attributes is modeled with probability distribution functions based on historic sales data or expected business in the future. The orders travel through the business process as defined in the simulation model, and when the orders reach a task which simulates the scheduling of customer the orders, specific availability quantities are searched in the availability outlook, which are then reserved for the order and are decremented from the availability outlook. The reservation (consumption) of specific availability can be decided by the various policies and rules, such the sourcing policy, scheduling polices and fulfillment policies. The reservation of availability outlook can also be determined by Availability Promising Engines described earlier. The ATP engines can be connected to the simulation model and communicate the optimal ATP reservation to the simulation model.

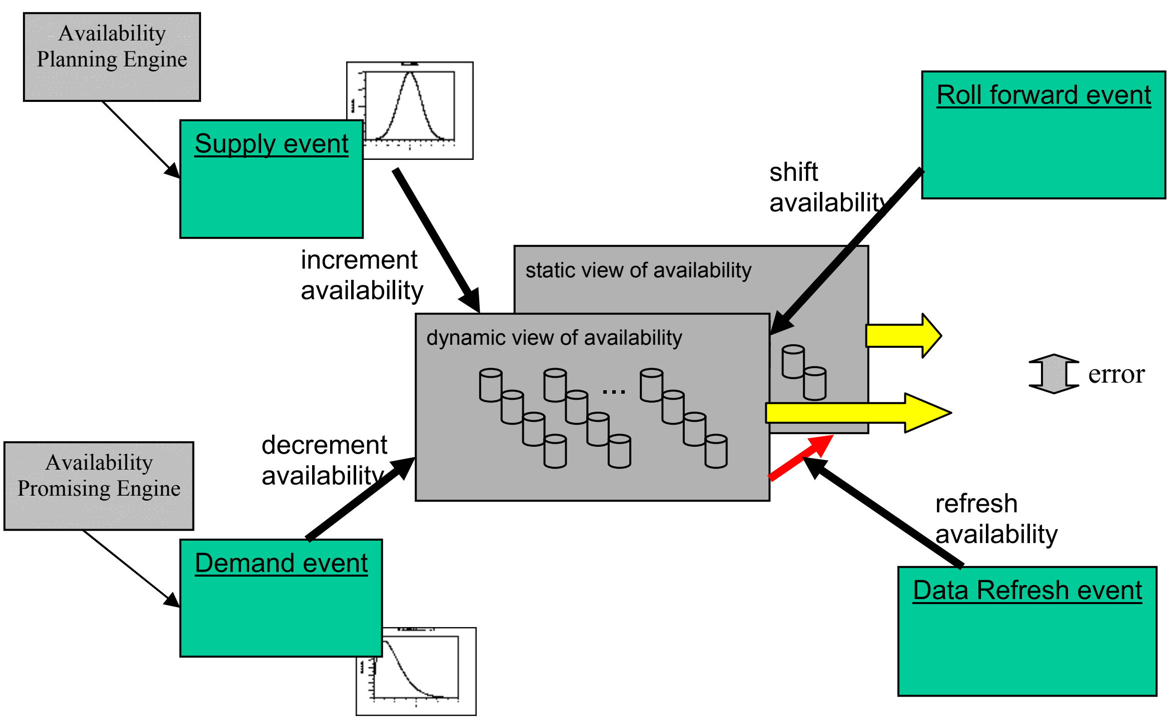

Figure 3: Multiple Events that Affect Availability

Supply Event

The supply event is a push-side of availability management, and it involves availability generation through schedules of production and procurement. The supply event is triggered in certain interval, e.g., weekly or daily, and it increments the availability outlook. As finished products or building block components are reserved when customer orders are scheduled and fulfilled, additional availability is added to the availability outlook through production or procurement. This activity, supply event, is planned in advance, e.g., months, weeks or days before the availability are actually needed in order to accommodate the lead time for production and procurement. As a result of the supply planning, the availability outlook is updated and replenished. The replenishment frequency can be a fixed interval such as daily, weekly etc, or it can be modeled using a distribution function. The replenishment quantity is typically determined based on the forecast of customer demand. The frequency and size of the replenishment are also decided by various replenishment policies. The allocation of availability outlook can also be determined by Availability Planning Engines, some of which described in section 1. These ATP engines can be connected to the simulation model and communicate the optimal ATP allocation to the simulation model.

Roll Forward Event

As simulation clock moves from a time bucket to another, the availability of products or components that have not been consumed are carried forward to an earlier time bucket. For example, the availability quantity of 2nd day moves to the availability quantity of 1st day, and that of 3rd day becomes that of 2nd day etc. Also, the availability quantity not consumed on the 1st day stays on the same day, assuming it is non-perishable. The roll-forward event can be generated in a fixed interval, e.g., daily or weekly, depending on the business environment.

Data Refresh Event

There are two instances of availability outlook; one representing the availability quantity at real time (dynamic view of availability, or physical availability), and another representing availability recorded in the availability database (static view of availability, or system availability). The system availability is the one that is used for scheduling of customer orders, and it not always accurate. The system availability is synchronized with physical availability only periodically because it is expensive to have IT architecture that allows real time synchronization. This synchronization between physical availability and system availability is modeled in the data refresh event. For example, the static view of availability is refreshed every few minutes, every hours, or even every few days.

The discrepancy between the physical availability (dynamic view of availability) and the system availability (static view of availability) causes the inaccurate ship date calculation. In our simulation model, the ship date is computed using both dynamic and static view of the availability, as shown in the Figure 3, and the inaccuracy of the ship date calculation from the system availability is estimated. The inaccuracy of ship date calculation is an important indication of customer service level. The data refresh event can be modeled as fixed interval event or randomly generated event described by a distribution function. The analysis on how the refresh rate impacts the ship date accuracy is described in the section 4.3.

4. Case Studies for SAM

4.1. Availability Management based on CTO vs. MTO Environment

In this scenario, one IBM's hardware businesses was interested in moving from MTO environment to CTO environment, but they weren't sure what will be the impact to the supply chain, specifically customer service level and inventory. For this case, we have used the AMST to evaluate the benefits of managing availability on component level vs. finished goods level for the business. Using the model we were able to quantify the improvement of supply chain performance with respect to order fulfillment rate, lost sales and inventory.

This business requires a high level of customer service. Customers configure products from available components at the time of e-shopping or at the time placing an order, they expect to have a quick response time for ship date quotation. The size of customer orders are highly skewed toward the end of quarter, that is, a relative small number of orders arrives in the beginning of a quarter (3 months), and more and more orders arrive toward the end of the quarter. The peak production and supply capacity are constrained. There are many uncertainties in this business including uncertainties in demand, order configuration and supply. The Availability Planning and Order Scheduling have been done at FG (Finished Goods) level in the past, but a switch to component level was being planned.

For this study, we focused on key configurable components that are typically constrained. We have not included many other components that are integral part of the product, computer, but not constrained, such power cable, case and keyboard. We considered 3 key component types for the modeling; Hard Drive (HD), System Memory (SM) and System Processor (SP). We modeled 6 specific HDs, 4 SMs and 5 SPs. Components in this environment are called Sales Building Block (SBB), and pre-configured finished goods are called MTM (Machine Type Model). For this simulation model, the availability outlook was allocated by product type and time period only. For modeling the pre-configured FG-based availability management (As-Is process), we allocated the availability to 120 (HD x SM x SP) buckets, each representing a specific configuration of using 1 HD, 1 SM and 1 SP, for each time period. The planning time period was by week, and its horizon was 13 weeks. For the SBB-based availability management (To-Be process), we allocated the availability to 15 (HD + SM + SP) buckets for each time period. For simplicity we assumed uniform probability of each component to be picked for a FG configuration. This is a HVEC business, which was described in the earlier section, and customer orders arrive without any advanced notice requesting as early as possible fulfillment.

Figure 4 and 5 shows the simulation results on promised ship date for the FG-based availability management and component-based availability management, for the simulation duration of 1 quarter (90 days). As it can be seen in the Figure 4, for the FG-based scenario, the lead time of promised ship dates fluctuate mostly between 1 week and 5 weeks from the time of order arrival, then goes up the 13 weeks and beyond toward the end of quarter. In contrast, as seen on the Figure 5, for the component-based scenario, the lead time of promised ship date is mostly 1 week, and only occasionally 2 weeks, a much better customer service. Table 1 summarizes and compares the order scheduling rate for the two scenarios. For the SBB based availability management, 95.77% of orders was scheduled for the first week, 99.94% for the second week, and 100% by the third week, while for the FG-based, 74.22% for the first week, 89.89% for the second week, and 94.91% by the third week. The simulation result clearly demonstrates that order fulfillment rate is higher with SBB-based scheduling than MTM-based scheduling. For the MTM-based scheduling, 3.29% of orders couldn't be scheduled within 5 weeks of order, and assuming that customers are not willing to wait 5 week, the 3.29% is considered to be lost sales.

For the SBB-based scheduling, all the orders that are scheduled can be fulfilled because specific component are reserved for orders when they are scheduled, and the components are available when it is time to be fulfilled. But for the MTM-based scheduling, 0.27% of orders that are scheduled couldn't be fulfilled because MTM availability is reserved for orders when they are scheduled, but the required components to assemble the MTM are not available when it is time to fulfill the orders.

Inventory of SBB for the SBB-based scheduling is 3,791 (for all the SBBs and first weekly bucket only) while that for the FG-based scheduling is 5,016, which is 24.5% higher than that of SBB-based scheduling. The simulation result clearly shows that inventory can be kelp lower with component based scheduling than finished goods based scheduling.

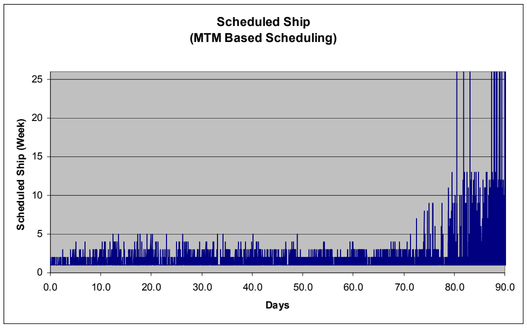

Figure 4. Promised Ship Date Profile for FG-based Availability Management

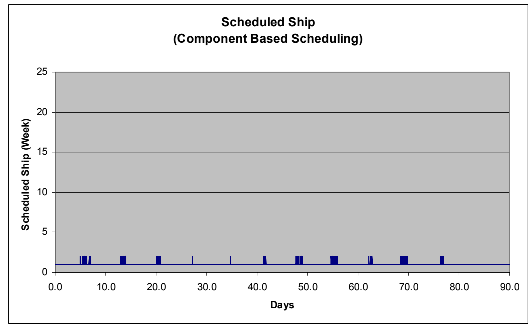

Figure 5. Promised Ship Date Profile for Component-based Availability Management

	Comp-Based Scheduling (cumulative)	FG-Based Scheduling* (cumulative)
Week 1	95.77% (95.77%)	74.22% (74.22%)
Week 2	4.17 % (99.94%)	15.68% (89.89%)
Week 3	0.06% (100%)	5.02% (94.91%)
Week 4	0.00% (100%)	1.29% (96.21%)
Week 5	0.00% (100%)	0.50% (96.71%)
> Week 5	0.00% (100%)	3.29% (100%)

Table 1. Order Scheduling Rate

We also simulated the two scenarios (FG-based and Component-Based) with 2 different supply variability, e.g. uncertainly of supplier commitment. We used 5% and 10% standard deviations of supplier commitment for requested supply quantity, and computed lost sales quantity and unfulfilled orders that are scheduled already. As seen in the Table 2 and 3, the lost sales quantity are larger when supply variability is larger, but the component-based scheduling is more tolerant to supply variability than the FG-based scheduling. Also, order promising accuracy is worse when supply variability is larger, but component-based scheduling is more tolerant to supply variability than the FG-based scheduling.

	Comp-Based Scheduling	FG-Based Scheduling
Lost Sales	0.00%	3.29%

Table 2. Lost Sales for Two Different Supply Variability

	Comp-Based Scheduling	FG-Based Scheduling
Inventory	3,791	5,019 (24.5%)

Table 3. Scheduled Order Unfulfilled for Two Different Supply Variability

4.2. Availability Management based on Different Demand Classes

In this scenario, one of IBM's hardware businesses was interested in managing availability based on new demand class, and they didn't know how the new demand class would impact their supply chain performance, specifically on their customer services and inventory cost. The business wanted to change from a demand class#1 representing 4 geographic demand regions to a new demand class#2 representing 8 new geographical demand regions. For this case, we also used the AMST model to evaluate the impact of the demand class change on supply chain performance.

We modeled and simulated 4 different scenarios based on different ways of availability allocation and order scheduling as shown in Table 4.

Scenario 1 is the old (As-Is) availability management process, where availability outlook is allocated based on 19 Product Types, 4 Sources of Supply, 4 elements of Demand Class#1 and 13 Weekly buckets. When an order is generated, the order is assigned with attributes, e.g., a product type, a source of supply, a demand class and the customer requested ship date (also called due date). For the scenario 1, the simulation model tries to schedule each order by searching for availability for a specific product, a source of supply and a demand class, and then the weekly bucket that corresponds to the customer requested ship date. If no availability is found, the model goes back to earlier weekly buckets until it find the availability. If availability is still not found, the simulation model looks for available in later weeks until it finds the availability. If no availability is found in any of 13 weekly buckets, the order is considered backlogged. For this case study, we simulated more than 100,000 orders which represent customer orders for the business for a year. From the simulation, we estimated the customer services and inventory holding costs.

	Allocation of Availability Outlook	**Constraint on Order Scheduling**
Scenario 1 (As-Is)	Product Type (19) Source of Supply (4) Demand Class1 (4) Weekly buckets (13)	No constraint
Scenario 2 (To-Be 1)	Product Type (19) Source of Supply (4) Demand Class2 (8) Weekly buckets (13)	No constraint
Scenario 3 (To-Be 2)	Product Type (19) Source of Supply (4) Weekly buckets (13)	Ceiling imposed by Product Type, Demand Class2 and Quarter
Scenario 4 (To-Be 3)	Product Type (19) Source of Supply (4) Weekly buckets (13)	No constraint

Table 4. Four Simulated Scenarios for Case Study #2

Scenario 2 is the new (To-Be) availability management process that the business would like to evaluate. For this scenario, availability outlook is generated based on 19 Product Types, 4 Sources of Supply and 13 Weekly buckets. But, in addition, it is generated based on 8 elements of Demand Class#2, which represent new geographic demand regions.

Scenario 3 is another new (To-Be) availability management process that the business would like to evaluate. For this scenario, availability outlook is generated based on 19 Product Types (19), 4 Sources of Supply (4) and 13 Weekly buckets. It is not generated based on neither Demand Clas#1 nor Demand Class#2. However, in this case a constraint is imposed when scheduling order. The constraint is a ceiling, which is a maximum allowed quantity for scheduling a specific product type and a specific demand class#2. The ceiling is usually imposed with a predetermined flexibility, 2% etc.

Scenario 4 is another new (To-Be) availability management process that is similar to the scenario 3, but there isn't any ceiling imposed for the scheduling.

For some of key data used in the simulation model are as follows. Customer orders are highly skewed toward the end of 13 week period. The number of orders in the first week of the quarter starts with about 4% of quarterly volume, gradually increases, and for last two week of the quarter the number of weekly order goes up to about 15% of quarterly orders. In addition to the weekly skew of orders, the weekly demand itself has a variability. The variability of component supply is also modeled. The customer requested ship date (due date) is also skewed in that a large portion of orders arriving early part of the quarter request orders to be shipped latter part of the quarter, and the orders arriving in the latter part of the quarter request the orders to be shipped within a few weeks before the end of the current quarter.

One of the key performance metrics we wanted to measure for this case study was scheduling delay. For this business, customer orders come with requested arrival dates (due date). Since the transportation lead time is known in advance based on the service level agreement with carriers, it is easy to figure out when the order should be shipped (requested ship date) so that the product arrives at customer's place on the requested arrival date. The scheduling delay here, therefore, is defined as the difference between scheduled ship date and requested ship date. The figures 6, 7, 8, 9 show the scheduling delays for the four scenarios for one product type. It is clear to see in the figure 6 and 7 that the scheduling delay gets worse when the demand class is changed from one that has less members (Demand Class#1) to one that has more members (Demand Class#2). This is obvious because when availability buckets are bigger it is easier to schedule orders against them than when the availability buckets are smaller. As it can be seen in the Figure 8, the scheduling delay is substantially reduced when the demand class is dropped from the availability allocation. However, the ceiling creates significant constraint in scheduling toward the end of quarter. Obviously when the ceiling is dropped (Figure 9) the scheduling delay at the end of quarter disappears. The scheduling delays for the four scenarios are summarized in Table 5.

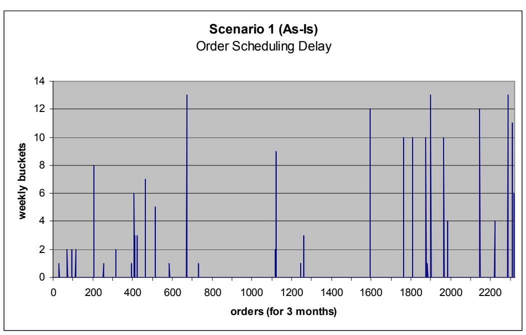

Figure 6. Order Scheduling Delay of Scenario 1 (As-Is)

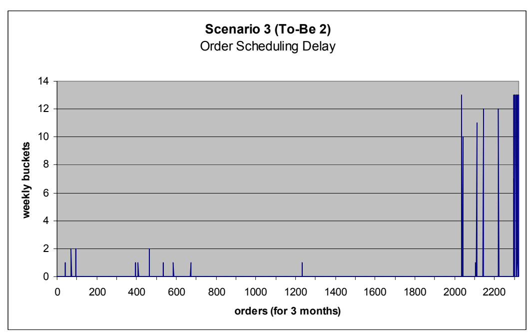

Figure 8. Order Scheduling Delay of Scenario 3 (To-Be 2)

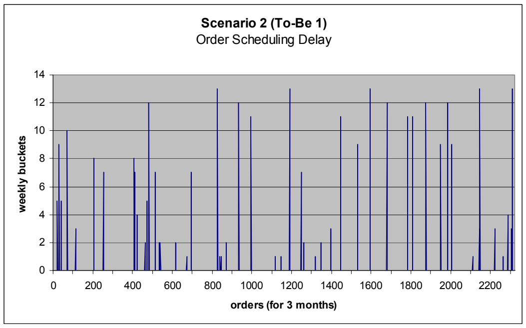

Figure 7. O rder Scheduling Delay of Scenario 2 (To-Be 1)

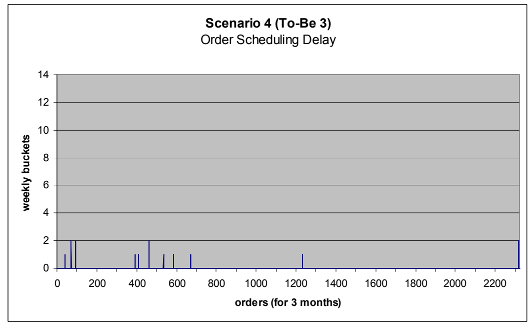

Figure 9. Order Scheduling Delay of Scenario 4 (To-Be 3)

Order Scheduling Dealy	Scenario 1 (As-Is)	Scenario 2 (To-Be 1)	Scenario 3 (To-Be 1)	Scenario 4 (To-Be 1)
wk0	72.10%	70.74%	78.25%	78.26%
wk1	12.25%	11.57%	10.38%	10.42%
wk2	4.64%	4.85%	2.73%	2.74%
wk3	2.71%	2.99%	2.66%	2.70%
wk4	2.87%	2.97%	3.03%	3.18%
wk5	2.18%	2.04%	1.50%	1.61%
wk6	1.33%	1.23%	0.57%	0.75%
wk7	0.62%	0.78%	0.16%	0.19%
wk8	0.14%	0.59%	0.03%	0.02%
wk9	0.12%	0.28%	0.02%	0.01%
wk10	0.12%	0.25%	0.05%	0.03%
wk11	0.17%	0.33%	0.09%	0.02%
wk12	0.23%	0.46%	0.11%	0.03%
>wk12 (backlogged)	**0.52%**	**0.95%**	**0.41%**	**0.04%**

Table 5. Order Scheduling Delay for 4 Scenarios

Another the key performance metrics for this case study was inventory holding cost. We assumed here that the holding a product for one year costs 20% of the sales value. Table 6 compares inventory holding costs of the four scenarios. The scenario 2 would cost $2.827 million more than the scenario 2 (As-Is). However, the scenario 3 and 4 would generate a substantial saving as compared with the As-Is scenario.

	Scenario 1 (As-Is)	Scenario 2 (To-Be 1)	Scenario 3 (To-Be 2)	Scenario 4 (To-Be 3)
Inventory Holding Cost	$13.135 million	$15.962 million	$9.405 million	$8.673 million
Inventory Holding Saving* w.r.t. Scenario (As-Is)	--	-$2.827 million	$3.730 million	$4.462 million

Table 6. Inventory Holding Costs for Four Scenarios

4.3. Balancing Accuracy of Promised Ship Date and IT Costs

In an ideal e-business environment, when a customer order is scheduled and a ship date is computed, the availability should immediately be reserved and not be available for future orders. However, in reality the availability data that are used for the scheduling the orders are not real time availability (physical availability), but they are availability information stored in an IT system (system availability). The availability data IT system (static view of availability) is typically refreshed (synchronized with real time availability) only periodically since it is very expensive to update the database in real time. Due to the potentially inaccurate view of the availability, some orders can't be fulfilled on the promised ship date. Thus, for certain customer orders, products are shipped later than the promised ship date thus resulting in a degree of customer dissatisfaction. Therefore, one of key decisions in availability management is to properly balance IT system (e.g., IT expense) and customer service level. In this work, we studied how availability fresh rate (IT system) impacts customer service level. The simulation study helped the business group making a critical business decision on refresh rate of availability, and avoided expensive investment of deploying new IT system.

The lead time to shipment is determined and provided to customer in multiple times during the customers' shopping process, at "web-speed". Customers make decisions on purchase based on the availability information (promised ship date) in addition to other criteria such as price and quality of goods. Once an order is placed, the customer expects the product to be delivered on the promised date. Since the promised ship date and its accuracy are directly related to customer service, it is very important to accurately project them before a new business process or its change is implemented.

In this case study, we also used AMST to evaluate how the frequency of availability data refresh affects the accuracy of availability information given to customers. Figure 10 compares ship date errors for four refresh frequencies, for orders arriving with three different demand classes for a specific business setting of the IBM hardware business. Table 7 also summarizes the simulation results. In average, the ship date error went down to 1.4% from 3.2% as the refresh frequency increases from once a day to four times a day.

Figure 11 shows the trade-off between ship date error and IT Cost for refreshing the availability outlook in the IT system. As it is shown, as the refresh rate increases from once a day to four times a day, the IT costs increase substantially. Although the general relationship between ship date error and IT Costs are not a surprise, the quantification of the trade-off is key information that business leaders need to have to make sound business decision on the availability management process. The right decision is the balancing the ship date error (customer service) and IT costs that is reasonable for a business at the time of analysis.

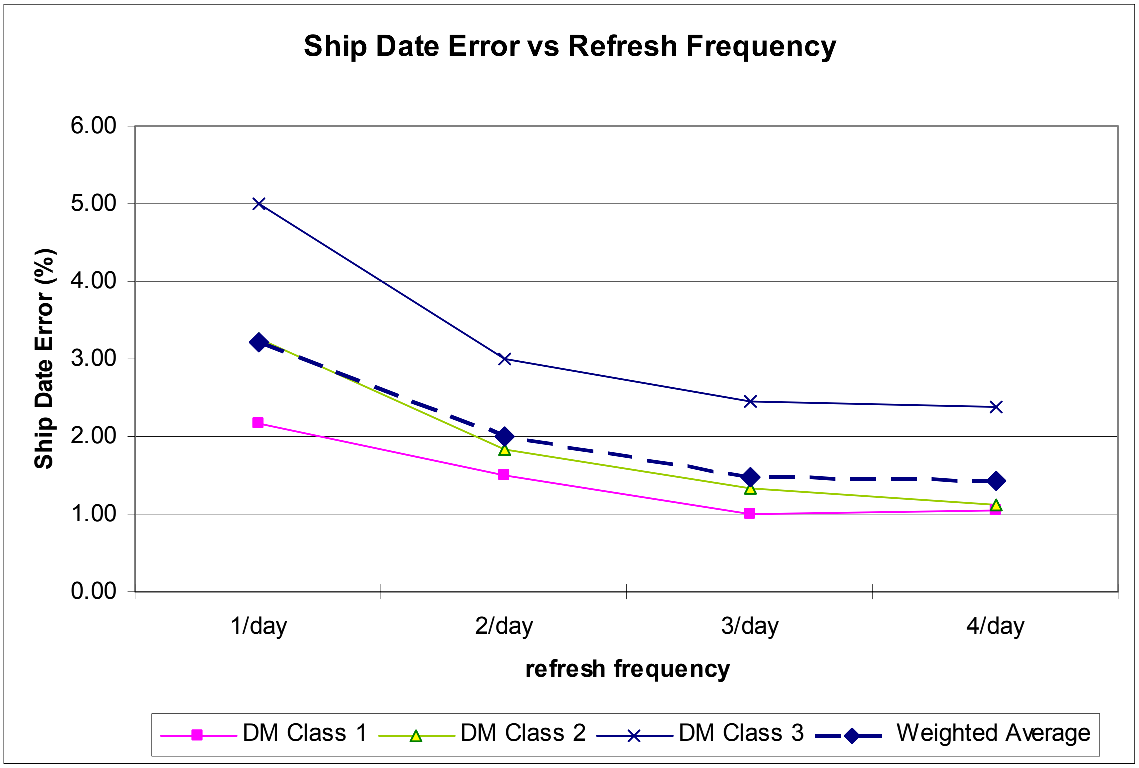

Figure 10. Ship Date Error for 3 Various Refresh Frequencies

	Ship Date Error			
Demand Class	**Once a day Refresh**	**Twice a day**	**3 Times a day**	**4 Times a day**
DM Class1	2.156%	1.511%	1.011%	1.044%
DM Class2	3.254%	1.841%	1.333%	1.127%
DM Class3	5.000%	3.000%	2.463%	2.389%
Weighted Average	**3.225%**	**1.997%**	**1.485%**	**1.419%**

Table 7. Ship Date Error Summary for Various Refresh Frequencies

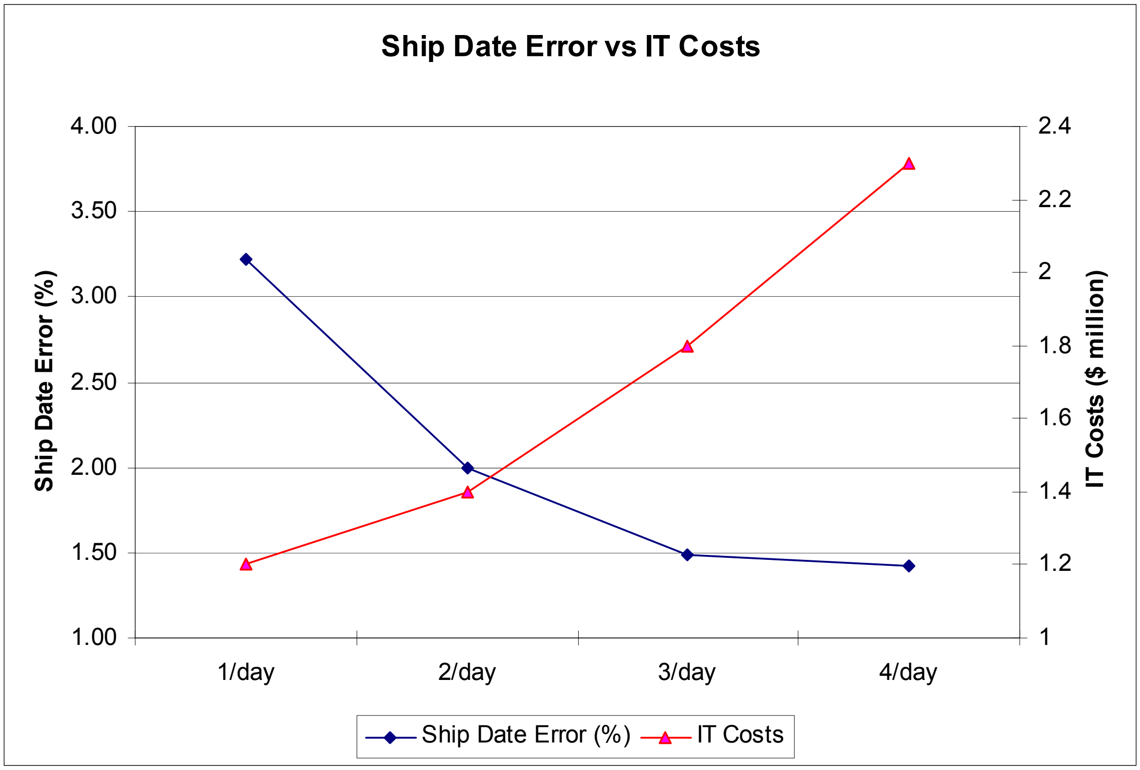

Figure 11. Trade-off between Ship Date Error and IT Costs

5. Concluding Remarks

Availability management directly influences key supply chain performance such as customer services and inventory. In the current dynamic, competitive business environment where organization has to continually adapt to accommodate customer's need, it is very important to be able to assess the existing availability management process and explore various ways to improve it. In this paper, we described the Availability Management Simulation Tool (AMST) that was developed for IBM's computer hardware businesses. The model simultaneously simulates the three main components of availability management process; generating availability outlook, scheduling customer orders and fulfilling the orders, as well as the effect of other dynamics in the supply chain. The tool has been instrumental in evaluating and deploying several availability management transformation opportunities in IBM.

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Guidelines to Practitioners

The AMST (Availability Management Simulation Tool) was developed using the simulation engine of IBM WBI Modeler ® (IBM Corporation). However, the capability can also be built using other commercially available discrete-event simulation modeling tools such as ProModel (http://www.promodel.com/), Arena (http://www.arenasimulation.com/), Witness (http://www.lanner.com/home/the_value_of_knowing.php) to name a few. Although several ATP engines have been developed by other researchers to optimize the push (Availability Generation) and pull (Order Promising) side of ATP, there hasn't been any tool that evaluates the effectiveness of such ATP tools as well as various policies in various order management environments. AMST is such a tool that can simulate the availability management process by simultaneously modeling many components and dynamics including ATP tools.

The core of the simulation model is described in the figure 3, which is a part of the order processing process where customer orders travel through. Figure 12 shows an overview of a simple availability simulation model we developed. In this sample model, the rectangles represent various tasks (and events), circles represent several views of availability outlook and the arrows represent the movement of artifact (customer orders in this case). Generation of orders (or on-line shopping) is modeled in the first rectangle on the left side of the figure 12, and general availability of product, features and price are also displayed to customer here. The orders then proceed to the next task where a specific product is configured from the availability of components. Ship date is also determined here in the availability check (shop) task, which accesses the IT system that contains availability outlook data. If the customer is satisfied with the ship date, the order moves to next step, the availability check (buy) task, and is submitted. A promised ship date is calculated again here using the availability outlook data and order scheduling policies. The submitted order goes through the order processing task in the back office and order fulfillment process, where the availability is physically consumed.

The tasks specified as rectangles in figure 12 can have certain processing time. They can also require certain resources such as an IT server, a part of whose resource is tied up in processing orders.

As it is common for many modeling work, a substantial time and effort are expected for collecting and validating data in developing a simulation model of the availability management process. The availability management simulation capability we described here is planned to be incorporated into a larger simulation tool that handles much bigger scope of supply chain management.

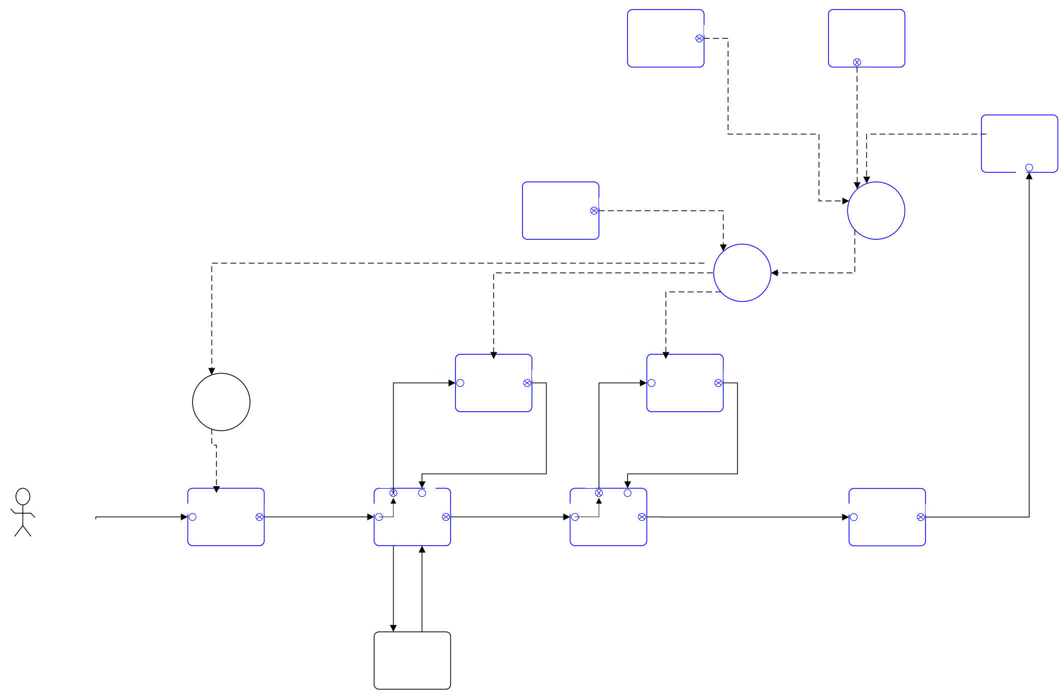

Figure 12. A Sample Availability Management Simulation Model

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