SUPPLY CHAIN PERFORMANCE UNDER TRANSIENT DEMAND INCREASES: A CASE STUDY SUPPORTING SUPPLY CONTRACT NEGOTIATION

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ABSTRACT
The advent and continued growth in the electronics and EMS (electronics manufacturing services) industry has precipitated research in this area in recent times. This paper addresses issues surrounding the development of supply contracts in the resulting outsourcing arrangements. A case study is presented which investigates exceptional occurrences in the form of transient demand upturns with little or no forewarning. The EMS provider wished to examine inventory holding and service level issues in this environment. The case study is described in some detail and initial experimentation is carried out using discrete event simulation to analyze how this demand, coupled with problematic lead time and sub-supplier capacity constraints affects the system. Results indicate that parameter interactions are non-trivial. In addition useful information from simulation modeling can aid in negotiations of supply contracts where OEMs wish to maintain service levels under reasonable supply chain costs.

Keywords: Simulation, Inventory Control, Transient Demand, Supply Contracts.

1. INTRODUCTION
In environments where production outsourcing exists, OEMs need to have assurance of supply. Along with high quality and low prices, meeting demand on time and in full has become a way of gaining a competitive advantage in a growing electronics market. EMS providers currently make up a major link in the electronic goods supply chain. The EMS market grew by 13.8% in 2005, which was over twice the growth experienced in the worldwide electronics market (6.1%). Electronics assembly, valued at $810 billion in 2005 has been predicted to reach a value of $1.1 trillion by 2010. If this growth was accurate the EMS industry would grow from $190 billion in 2005 to $328 billion in 2010, (DATAMONITOR 2006). This growth has precipitated investigations in the literature into how EMS providers operate such as (Zhai, Shi et al. 2007).

Here, the issue of supply assurance during occurrences of transient demand was addressed with the aim being to support contract negotiation between an OEM and contract manufacturer/EMS. Specifically, transient upturns in end-item demand with little or no warning experienced by an OEM and relayed to an EMS provider is addressed. Supply contracts are used to define the operating conditions that the participating members agree to and for these conditions they set out the acceptable supplier service levels. (Das and Abdel - Malek 2003), note that a supply contract is the key document defining the parameters under which the parties operate and it is the robustness and flexibility of such documents that will determine the success and stability of the partnership. A contract manufacturer faced with stable demand requirements from an OEM with given assurances of supply from its suppliers can agree to meet service level requirements laid out in the contract. Under these conditions the OEM is reasonably assured of supply. However, the occurrence of unforeseen transient behaviour in the supply chain conditions can affect this stability. Through collaboration the OEM can work with the contract manufacturers and sub suppliers to attain the specifications of the supply contract as is the case with the computer manufacturer Dell. Dell successfully practices heavy reliance on outside suppliers and contract manufacturers Kraemer and Dedrick 2005). It is also noted that Dell invest heavily in advanced manufacturing and logistics capabilities incorporating advanced information systems to help use information as a substitute for inventory, with positive market results.

Supply chains are subject to numerous factors that can affect performance. (Cigolini, Cozzi et al. 2004), is one paper that suggests a framework with which, managers can decide what environmental characteristics to attend to when designing their supply chain management policy. While some are controllable by specific participants in the supply chain, others tend to lie of their control, such as demand (disregarding seller initiated disruptions such as discounts, for example). Such factors are labelled environmental conditions. The demand parameter constitutes an important input to models in general in supply chain management as it is almost ubiquitous regardless of the kind of modelling approach. (Bookbinder and Cakanyildirim 1999), applied the simplest form of demand input in a model which investigated random lead times and expedited orders in (Q, r) inventory systems. This model consisted of a two-echelon system with a known and constant demand rate. This is generally referred to as a constant deterministic demand parameter and is simply a point estimate of periodic demand. The other main form of demand modelling is stochastic demand as employed by (Ayanso, Diaby et al. 2006). Here, demand in each period consists of a sample taken from an empirical distribution with chosen parameters. Further to this is non-stationary demand which can be both deterministic and stochastic. In this case the point estimate or mean of the distribution can shift from period to period. This is often seen when there are seasonal variations in the base level of demand for a product. In addition to this we have found some papers however that either model demand or at least consider the importance of it with greater detail based often on actual market information across a number of industries.

(Hwarng, Chong et al. 2005), undertook a large study on a real, complex supply chain. One of the aims was to evaluate the impact of simplifying demand assumptions under different supply chain configurations. Raw data collected over a period of more than three and a half years was used, taken from a pharmaceutical company. The demand data for a single product was used to derive the demand inputs for the model. Distribution fitting software, Stat::Fit was used to determine the most appropriately fitting distributions and parameters for the data and these were input to the model. Chi-Square and Kolmogorov- Smirnov values were given to indicate the goodness of fit of the distributions to the data. The results of the experiments indicated a difference in output when distributions based on case study data were used as opposed to using empirical distributions. Higher backlogs resulted of up to approximately 5% along with average stock increases up to 70%. However because of the specificity of the paper on a supply chain with quite a highly complex structure and unique data the results cannot readily be applied to many other supply chains. The approach was a singular case study, without an attempt to generalize to other scenarios. This was deliberately done to serve the purpose of highlighting the dangers of arbitrarily choosing levels of stochastic inputs.

Another demand input method that has received minor research in comparison to the two main approaches is detailed in (Bartezzaghi, Verganti et al. 1999a). They investigated the ability of three forecasting methods to deal with irregular and sporadic - termed lumpy - demand. The forecasting techniques examined were; exponentially weighted moving average, early sales and order over planning. The latter two methods make use of future demand information rather than just historical data and are described in some detail in the paper. Performance of each of the methods was judged on the mean absolute deviation (MAD) of the forecast error. The results helped form a framework whereby each forecasting method was given a domain of applicability relating to the prevailing conditions of lumpy demand.

Transient demand characterized by exceptional, unpredicted increases (pulses) can result in massive reductions in service levels, i.e. meeting demand on time in full (OTIF). In addition, costs to the system due to backorders can dramatically increase and persist long after the transient demand has passed. While demand input is quite comprehensively investigated in supply chain management literature, demand of this nature, has been previously unfound. The demand pulses which characterized the system can be defined by 3 main elements as shown in Figure 1; magnitude, duration and shape. Time is depicted in weeks unless otherwise noted.

Figure 1 illustrates that the pulse can be any real positive multiple of the nominal demand in magnitude added to the nominal forecasted demand and may also extend over an interval of a number of weeks thus extending duration. Figure 2 further illustrates that the pulse can take varied forms. Shown here are two examples which equate to; (a) a set of 4 spikes of equal magnitude and, (b) a ‘ramp’ pulse of increasing amounts over a time of 4 weeks. A constant deterministic figure, nominal demand derived from the OEM forecast made up the demand in all the other periods of the model. In addition, there may be some kind of positive demand lead time that gives advance notice of the pulse. This advanced demand information (ADI) can positively affect supply chain performance to varying degrees as noted by (Bourland, Powell et al. 1996), depending on how it is utilized.

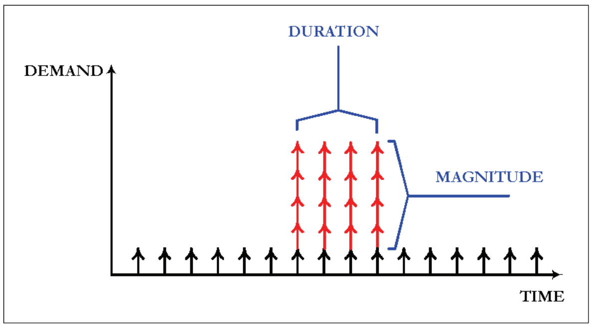

Figure 1: Demand Characterization

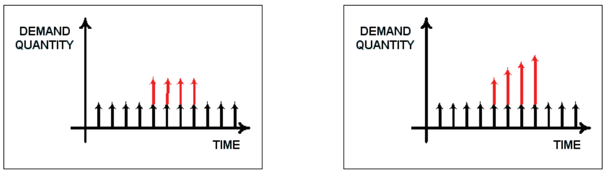

Figure 2: Additional Demand Pulses

These demand pulses are a form of unexpected exceptional events. As noted by (Hwang and Tang 2004), exceptions can be of two types;

- Expected,
- Unexpected.

An expected exception is known to occur occasionally or periodically and can be handled routinely with measures to facilitate them put in place at design time. However, other exceptions such as the demand pulses defined and applied in this experimentation are a result of unforeseeable changes in the supply chain environment. This demand is experienced by a production supply chain based on a case study model of an EMS provider. The segment of the supply chain in question consisted of the OEM experiencing end-item demand passed on to the EMS who in turn sourced components for manufacture from a range of sub-suppliers. The problem area in the supply chain involved the assembly of an electronic medical device for a large OEM from various components for shipping to the OEM for final configuration for individual end-item markets. Figure 3 illustrates the supply chain and the focal point of the investigation. A turnkey arrangement contract existed between the OEM and contract manufacturer. This is defined by (Kim 2003), as an arrangement where the OEM pre-approves the sub-supplier list for the contract manufacturer from whom the components for the product must be sourced. Therefore, supplier selection was not available to the contract manufacturer in this supply chain similar to (Smith, Agrawal et al. 2003), for example. This is not uncommon in the area of life sciences related products where strict legislation regularly exists for both design and production.

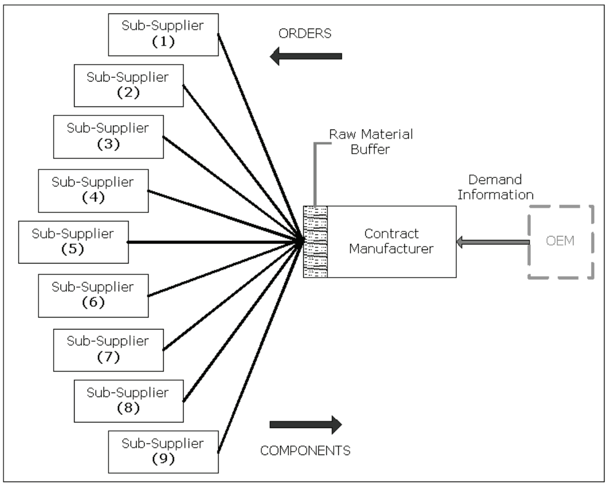

Figure 3: Case Study Supply Chain

This forced the contract manufacturer to operate with a set of sub-suppliers not of its own choosing. Thus, meeting OEM demands became a more complex issue for the contract manufacturer. The contract manufacturer was forced to plan its production around the production capacities and lead times of its sub suppliers. For these reasons it was found that the input factors of sub-supplier capacity and component procurement lead time also impacted heavily on the performance of the supply chain.

The study of lead time variability in supply chains is almost as popular as that of demand. There is an important segregation that must be made in the study of lead times in supply chain literature. Many papers such as (Chu, Yang et al. 2005), view lead times as an output from a supply chain system and that an aim of supply chain management should be to minimize lead times. In addition (Holweg, Disney et al. 2005), note that long lead-times in vehicle manufacture in Europe are a vital hindrance in the increased production of build-to-order products. For this reason many papers look toward reducing lead-times thus viewing them as an output of the system. This is the case in (de Treville, Shapiro et al. 2004), which aims at improving supply chain performance by reducing lead-times.

However, lead-times are also inherent in supply chain systems. For example, while production lead-times can be reduced or affected by a number of means such as production lot size for example (Ben-Daya and Hariga 2004), transportation lead-times faced by companies often cannot be attended to in a similar fashion. Similar to (Waters 1992), (Chu, Yang et al. 2005), clarify that lead times are made up of a number of smaller components each with differing attributes and each having differing abilities of being reduced. Lead time components such as transportation periods via sea shipping methods for example, fall under the previously referenced term of environmental conditions in the supply chain. Essentially, short of advances in the field of transporting physical stocks from one location to another, it is not possible to affect these lead times and therefore firms must incorporate them into their planning process.

There were 13 components noted as being key to the manufacture of the product in the case study as indicated in Table 4.1. Sub-supplier production capacity is expressed as a percentage of the nominal forecasted demand. In general, components for the device were classified as either *A B* or *C* depending on criteria regarding their importance.

Table 1: Case Study Lead Times and Capacities

Item	***a***	***b***	***c***	***d***	***e***	***f***	***g***	***h***	***i***	***j***	***k***	***l***	***m***
Lead Time (Wks)	8	7	7	13	12	4	8	12	22	20	2	2	8
Capacity %	119	167	167	248	159	167	110	222	120	248	167	167	248

These criteria covered such aspects as component price, contribution to the product and also specificity to particular products/ease of redeployment to other products. Class-*A* components were the most important and were the only component type considered worth investigating in the context of case study according to the contract manufacturer. At the time of initiating the case study, the contract manufacturer actually had little information regarding production capacity, even from the sub-suppliers of its 13 class-*A* components associated with this product. Within these 13 components the associated lead times were as low as 2 weeks and as high as 22 weeks with a broad dispersal in between. Such varied lead times complicated coordination of shipments and buffer allocations at the contract manufacturer. While lead-times were known and treated as deterministic in the system they were sub supplier dictated. Lead times between the sub supplier and supplier were defined as the interval between the placing of an order with the sub-supplier until the shipment arrives at the supplier, similar to (Oke and Szwejczewski 2005).

2. SIMULATION MODEL

The information from the case study was used to build a discrete event simulation model to analyze the supply chain performance. The supply chain model was built using an object orientated simulation package, eM-Plant. There were a number of reasons for choosing this piece of software. eM-Plant models in an object oriented framework which allows for the easy replication of objects such as the similar but not identical sub-suppliers in the supply chain in question. The ability to use the ActiveX object to link to MS Excel allowed for easy transfer of the output data for further analysis. Finally, the flexibility of manipulating the standard objects' behaviour using eM-Plant's programming language (SimTalk) was fundamental to the choice of the package to model the supply chain. SimTalk is a C based programming language that allows the model builder to customize the functions and interactions of the objects which make up the model. In order to model the supply chain, interaction with the contract manufacturer was undertaken including;

- Meetings both on and off-site with key personnel at the contract manufacturer facility,
- The general plant manager was the initial point of contact in the company and provided much of the background information to the case-study setting,
- The planning and inventory manager then became the project specific point of contact. This person was in a position to supply company data and information on inventory movement.

The simulation model consisted of 9 sub-suppliers supplying non-competing components into a single contract manufacturer, as illustrated in Figure 3. The OEM involvement in the model was restricted to a supply of demand information received by the contract manufacturer; there was no processing at the OEM. In addition it was assumed that there was a set of inexhaustible external suppliers to the sub-suppliers. 13 class-*A* components were supplied to the contract manufacturer. One sub-supplier furnished 5 component types and the remaining sub-suppliers each supplied 1 type. Each component type was subject to an individual lead-time as defined above. Buffer minimum requirement levels applied to all component types regardless of the associated lead times or capacities. Assumptions regarding some of the processes in the supply chain had to be made in lieu of more detailed production and supply chain information;

- It was assumed that 100% of the components shipped to the contract manufacturer arrived in usable quality,
- Production at the contract manufacturer could not exceed the minimum component in-stock quantity in any given period. Production of an end-item unit only commenced when sufficient quantities of all components were available,
- Backorders occurred at all locations,

Based on the problem formulation above a number of objects were developed in the simulation environment. Figure 4 shows the main graphical user interface (GUI) for the model at the highest level.

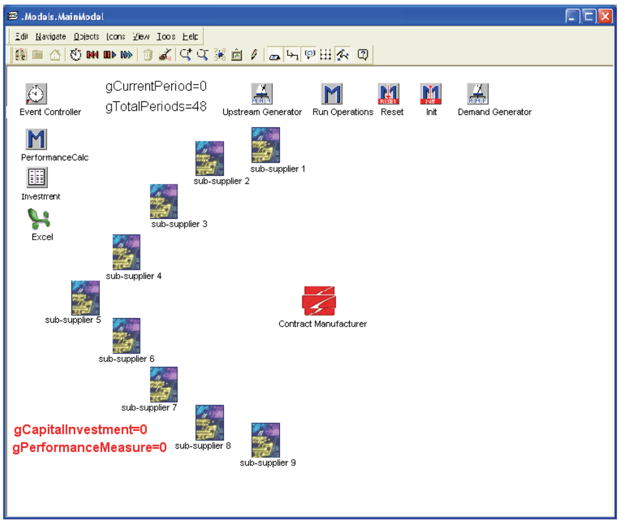

Figure 4: Simulation Model Main GUI

In the same way that the main model interface shown above, is a collection of objects located within a frame, each of those objects (sub-suppliers and contract manufacturer) are similarly a frame with a collection of objects within them. By double clicking on one of these objects a separate frame is opened and access is given to the individual objects that are constituents of it.

Figure 5 illustrates the contract manufacturer frame. Its behaviour as a player in the supply chain is defined by the objects within it, and their relationships to each other and the objects within the sub-suppliers etc. The contract manufacturer has three main functions;

- demand is experienced and orders are allocated to the master production schedule (MPS),
- components are received and added to the "instock" (raw material) buffer,
- production of end-item units takes place.

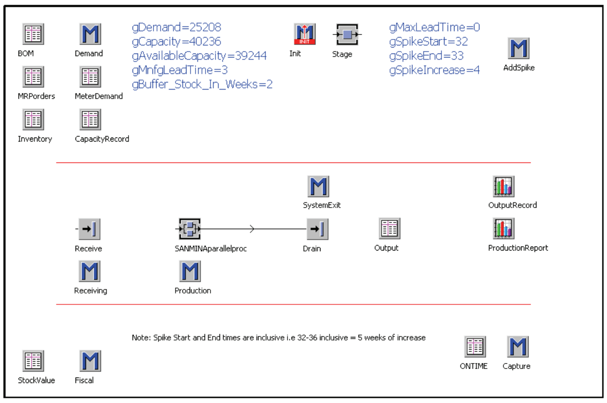

Figure 5: Simulation Model Contract Manufacturer Object

Historical information was gathered over time in each simulation run regarding production, backorders and costs at the contract manufacturer facility. At the end of a simulation run the information was collated for extraction to MS Excel. This was carried out using the code in the ***PerformanceCalc*** and ***Excel*** objects shown in Figure 4.

The sub-suppliers to the model were all of a similar construction to each other but had attributes that differentiated them from each other. These differentiating attributes were the production capacity, the lead time to the contract manufacturer and the component type produced. In the case of one of the sub-suppliers they in fact supplied multiple components as described previously. The replication functionality of the simulation tool enabled us to generate all nine sub-suppliers relatively easily from one parent object. Figure 6 depicts an example of a sub-supplier. The sub-suppliers produced the components used to make the end-item product. Orders were processed based on the MPS requirements generated at the contract manufacturer. Production took place based on these orders with allowances for production capacity. Backorders in any given period i were added to demand for period (i + 1). However, as with all backorders in the system there was no differentiation between freshly generated demand and outstanding backorders. The cumulative total of required parts was the effective demand figure. This did not affect the model as each sub-supplier only fed the single contract manufacturer and therefore prioritization was not an issue.

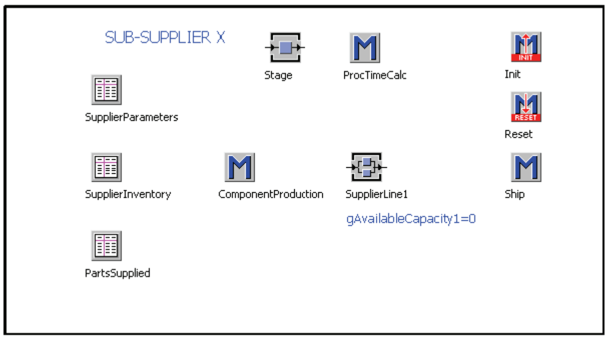

Figure 6: Simulation Model Sub-Supplier

The sub-supplier object tracks the list of part types supplied by the particular sub-supplier. In addition the functions of component production and shipping are handled and the historical inventory and cost data is recorded in the entity for results. Similar to the contract manufacturer the ***PerformanceCalc*** and ***Excel*** objects are used to extract the information from the individual sub-suppliers at the end of each simulation run. The functions of the sub-supplier can be surmised below;

- Orders for the period are picked up from the contract manufacturer MPS and backorder requirements if any are added resulting in the effective demand for the period,
- Production is launched equal to effective demand, production capacity allowing,
- Inventory and backorders are updated,
- WIP that has completed its cycle of processing and shipping triggers the release and is moved into the raw material buffer (instock) at the contract manufacturer.

The number of periods defining the model run-length was set by a global variable in the main model object. In addition there was code which initialized the model at the beginning of each run. All of the experimental data for each run (scenario) of the model was held in an internal database within the simulation model. Before each run was made the particular inputs were initialised in the model, setting the buffer levels, lead times and capacities. The demand was then created for the entire simulation run, based on nominal demand as detailed earlier. A periodic generator governed the triggering of each of the actions carried out in the model. A group of code "Run Operations", (shown in Figure 4) then called the subsequent code in their order of occurrence. Finally a "Reset" function ensured that the model was essentially cleaned at the end of a run in preparation for the initialization of the next run.

Part of the initialization regarded the warm-up period for the model, illustrated with a simplified example in Figure 7. Orders to the sub-supplier with the longest lead time began in period 0 and the entrances of orders were then staggered for the other components based on the lead time. Thus, the first order of components all arrived at the contract manufacturer at the same time. At this point the model was coded to being production at the contract manufacturer and a steady supply of components then arrived period by period.

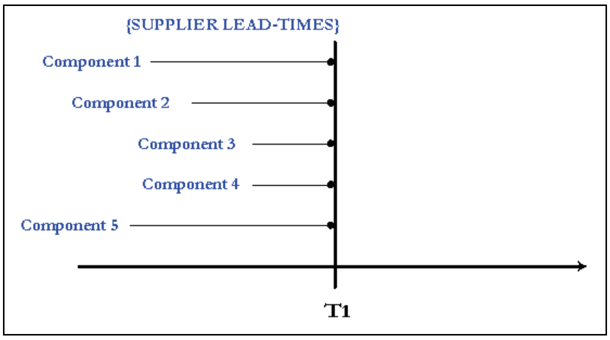

Figure 7: Forward Planning Vs. Lead Times

2.1. Performance Measures

As stated by (Kaipia and Tanskanen 2003), the only meaningful service level is from the retailer to its customers because this is what measures the performance of the supply chain as a whole. Because of the perceived importance of service level in the eyes of the OEM, the contract manufacturer needed access to information on backlogs in the system. The backlogs were created when backorders occurred. A service level metric was used to judge the system performance that was developed in conjunction with the plant manager at the contract manufacturer.

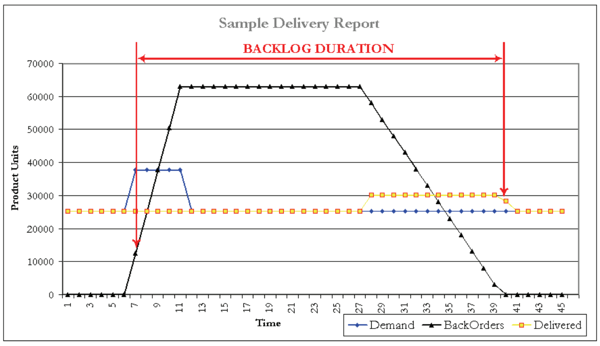

Figure 8: Definition: Backlog Duration

Figure 8 illustrates the key performance indicator (KPI), 'Backlog Duration'. This is defined as the interval in time from the point where backorders in the system appear as a result of the demand pulse to the point where the backorders return to zero. It is anticipated that the backlog duration is affected by component procurement lead times, sub-supplier capacities, buffer minimum requirements and the form of the demand pulse.

3. CASE STUDY EXPERIMENTATION

The case study experiments were based on the numerical data supplied by the contract manufacturer for the current supply chain configuration. The first requirement of the contract manufacturer was a simple one; to examine the effect of various minimal buffer requirements on backlog duration.

3.1. Case Study Results

The results corresponding to the four demand input scenarios across the buffer sizes are shown in Figures 9 to 12. In scenario A – Figure 9, when the supplier was faced with a demand pulse of 1 week in magnitude in addition to the regular demand, the absence of buffer stock resulted in all required goods backlogged not being outputted for 29 weeks. However, a minimal buffer requirement of just 1 week of components ensured that the delay was reduced to the minimum length of time, equating to the production lead-time at the supplier, 3 weeks.

Scenario A	Spike = 1 Week	
Buffer Size in Weeks	Investment Value	Backlog Duration
0	0	29
1	948,554	3
2	1,897,108	3
3	2,845,663	3
4	3,794,217	3
5	4,742,771	3
6	5,691,326	3

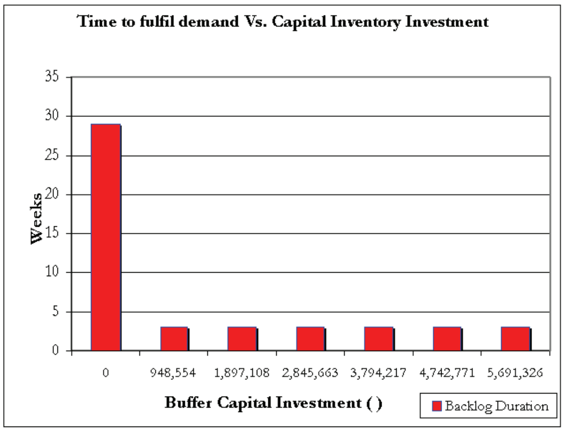

Figure 9: Scenario A

Scenario B	Spike = 2 Weeks	
Buffer Size in Weeks	Investment Value	Backlog Duration
0	0	34
1	948,554	29
2	1,897,108	3
3	2,845,663	3
4	3,794,217	3
5	4,742,771	3
6	5,691,326	3

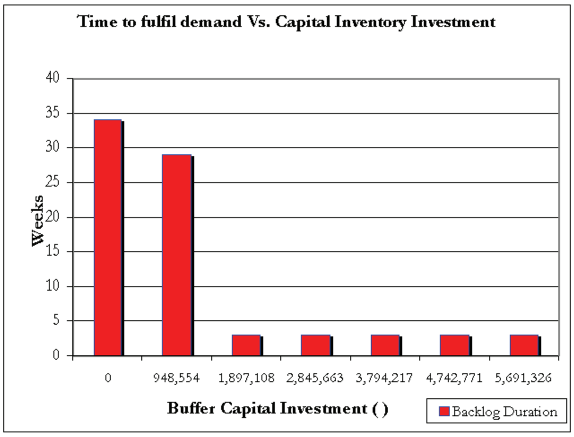

Figure 10: Scenario B

Minimal buffer requirements greater than 1 week resulted in similarly reduced backlogs but simultaneously resulted in over inventory and thus unnecessary costs at the contract manufacturer echelon. Most notable in scenario B – Figure 10 was the only marginal increase in backlog duration due to a doubling of the demand pulse.

Scenario C	Spike = 4 Weeks	
Buffer Size in Weeks	Investment Value	Backlog Duration
0	0	44
1	948,554	39
2	1,897,108	34
3	2,845,663	29
4	3,794,217	3
5	4,742,771	3
6	5,691,326	3

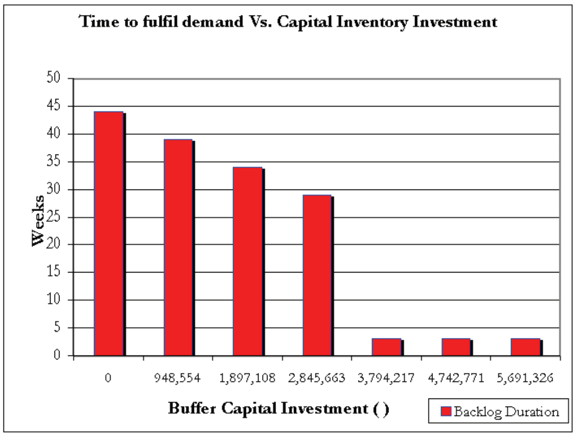

Figure 11: Scenario C

While a 1-week pulse created a backlog duration of 29 weeks, shown in Figure 10, the 2-week pulse only marginally increased the backlog by 5 weeks. This trend is similarly seen across the other scenarios depicted in Figures 11 and 12.

Scenario D	Spike = 8 Weeks	
Buffer Size in Weeks	Investment Value	Backlog Duration
0	0	64
1	948,554	59
2	1,897,108	54
3	2,845,663	49
4	3,794,217	44
5	4,742,771	39
6	5,691,326	34

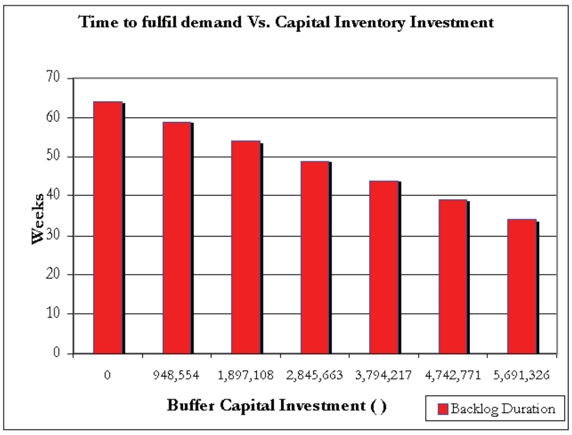

Figure 12: Scenario D

It was clear from the data outputted in the case study that for every week's worth of inventory held, the backlog duration was reduced by 5 weeks under the demand impulse. This was most notably illustrated in Figure 12. The results also indicate that regardless of buffer levels, sub-supplier production capacities or lead times; if the contract manufacturer was production capacitated, this would override any measures taken to reduce the backlog durations. This was intuitive but important for further experimentation when assessing the interactions of the various input parameters.

4. CASE STUDY CONCLUSIONS

The results of the case study indicated potential benefits of modelling supply chain environments at the contract negotiation stage, specifically incorporating negotiations surrounding transient demand upturns or other exceptional occurrences. Without proper precautions, even the small demand pulses can lead to inordinate backorder intervals. The case study provided a snapshot of a multi sourced supply chain under a set of input parameters taken from a segment of an industrial supply chain and in this respect was quite case specific. With fixed capacities and lead times it was evident that the increasing buffers led to linear reductions in the backlog durations to the system. After examining the results in detail and taking the replenishment rates at the buffers into account, there were found to be non-trivial interactions between capacities and lead times in conjunction with minimum buffer quantities.

Future work has been carried out on the system incorporating more detailed input and output analysis. Costs have been expanded upon to include actual inventory costs in the system over time coupled with backorder costs between the contract manufacturer and the OEM. In addition, stochastic demand and lead time inputs have been considered in the supply chain. This includes the use of previously tested empirical distributions from literature and also the analysis of real data from the supply chain. This input data has been analysed using the statistical software package MINITAB to uncover possible trends in demand data and/or the prevalence of certain empirical distributions when modelling demand data. Work in this area is ongoing.

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