Supply chain dynamics in healthcare services

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Abstract

Purpose – The purpose of this paper is to analyse health service supply chain systems. A great deal of literature is available on supply chain management in finished goods inventory situations; however, little research exists on managing service capacity when finished goods inventories are absent.

Design/methodology/approach – System dynamics models for a typical service-oriented supply chain such as healthcare processes are developed, wherein three service stages are presented sequentially.

Findings – Just like supply chains with finished goods inventory, healthcare service supply chains also show dynamic behaviour. Comparing options, service reduction, and capacity adjustment delays showed that reducing capacity adjustment and service delays gives better results.

Research limitations/implications – The study is confined to health service-oriented supply chains. Further work includes extending the study to service-oriented supply chains with parallel processing, i.e. having more than one stage to perform a similar operation and also to study the behaviour in service-oriented supply chains that have re-entrant orders and applications. Specific case studies can also be developed to reveal factors relevant to particular service-oriented supply chains.

Practical implications – The paper explains the bullwhip effect in healthcare service-oriented supply chains. Reducing stages and capacity adjustment are strategic options for service-oriented supply chains.

Originality/value – The paper throws light on policy options for managing healthcare service-oriented supply chain dynamics.

Keywords Supply chain management, India, Health services

Paper type Research paper

Introduction

The service sector is becoming increasingly important worldwide. For instance it is the largest and most rapidly growing US economy segment. According to the planning report prepared by US National Institute of Standards and Technology, it accounts for roughly three-fourths of value-added GDP. Value added means enhancements supplementing a product or service by a company before the product is offered to customers. The service sector has been growing at about ten times the rate of non-service sectors (Leech *et al.*, 1998). Harrington and Harrington (1995) defined service process as one where the main contribution is welfare of others and provides an intangible commodity. Service-oriented supply chain management is concerned with capacity management in the absence of finished goods inventory (Anderson and Morrice, 2000). The final stock in a manufacturing organization is termed a finished goods inventory.

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There has been significant research on managing finished goods inventory supply chain dynamics (e.g. the bullwhip effect - defined as amplifying demand fluctuations as we move from customer to manufacturer in a supply chain) (Lee *et al.*, 1997; Chen *et al.*, 2000; Baganha and Cohen, 1998). However, little research exists on managing capacity in the absence of finished goods inventory. Anderson *et al.* (2000) investigated bullwhip effects in capital equipment (used to manufacture a product, provide a service or used to sell, store and deliver merchandise, having an extended life so that it is properly regarded as a fixed asset) supply chains and similar service-oriented supply chains. They found that amplifying demand fluctuations in capital equipment supply chains, e.g. machine tools, is particularly large relative to that seen in component parts supply chains.

The mortgage service game, a simulation developed by Anderson and Morrice (2000) to teach service-oriented supply chain management principles, could be used to complement the Beer distribution Game, a simulation game created by MIT Sloan Management School professors in early 1960s to demonstrate several supply chain management key principles in a supply chain management course that covers both finished goods inventory and service management. Furthermore, the Mortgage Service Game can be used to illustrate behavior such as the bullwhip effect, the impact of local changes as reduced capacity adjustment time and information sharing impact on supply chain management principles in a make-to-order environment. Notably, little research exists on managing supply chain dynamics in the absence of finished goods inventory. However, some related work exists in the queuing theory literature (Rosberg *et al.*, 1982).

Related literature

There is a growing research interest in the supply chain management field (Sahay *et al.*, 2006; Fawcett *et al.*, 2008; New, 1997; Cox, 1999). Nevertheless, there exists relatively less literature on service-oriented supply chain management. Phippen *et al.* (2005) experimented in service orientation's feasibility to achieve dynamic, late-binding service architecture. Brashier *et al.* (1996) examined the total quality management/ continuous quality improvement (TQM/CQI) health-care industry literature and determined the common threads that exist in successfully implemented programmes. Rosberg *et al.* (1982) developed a model for optimally controlling first stage service capacity in a tandem queue by selecting the first stage service rate as a customer function at both stages in order to minimize waiting costs at the two stations.

Related work also exists in the job shop literature, particularly Graves (1986), who examined lead-time in a job shop using a control approach. Nicholson *et al.* (2004) addressed managing inventory costs in healthcare settings. They compared inventory costs and service levels in an in-house three-echelon distribution network vs an outsourced two-echelon distribution network. They report that outsourcing trend to distribute non-critical medical supplies directly to hospital departments using the two-echelon network led to inventory cost savings that do not compromise service quality.

Gebauer (2008) studied robust management practices for positioning pharmacies as healthcare providers. His article presented a framework for repositioning health service supply chain pharmacies. The main tools for framework development are two polar-typed case studies on initiatives to develop healthcare services and feedback models, which capture the rich interactions among basic structures for improving service development and decision-making processes, and mental models. Exploring these interactions leads to different problems during forming and implementing initiatives to develop health services.

The management policies we outline are not exhaustive. They highlight potential directions that can result in a management contribution towards advancing decision making in the healthcare sector. Because repositioning pharmacies as healthcare providers illustrates increasing service orientation in typical retail companies, the findings can be transferred into the general retailer context. Veronneau and Roy (2009) examined solutions to complex global cruise ship supply chain management by studying a large Florida-based global cruise company practice in re-supplying ships globally. The study focused on cruise ship supply chain characteristics and best practices for managing that global service supply chain. Their 24-month field study equally divided between time on cruise ships and time at the head office complemented by 19 formal semi-structured interviews with directors and managers within the cruise company supply chain management department. Their findings have implications for managing complex global service supply chains in such settings as humanitarian/ emergency and resort/tourism.

Demirkan and Cheng (2008) studied services supply chain consisting of one application service provider (ASP) and one application infrastructure provider (AIP). The AIP supplied computer capacity to ASP that in turn sells value-added application services to the market – characterized by a price-sensitive random demand. The ASP's objective is to determine optimal service price and optimal capacity to purchase from the AIP. The AIP's goal, on the other hand, is to maximize profits from selling capacity to the ASP. They examined supply chain performance under different coordination strategies involving risk and information sharing between ASP and AIP. Managerial insights from the model are most importantly an effective decentralized mechanism to maximize the overall supply chain performance. If this effective mechanism is absent then it is better to let players closer to the market coordinate the supply chain.

Building on service management, behavioural decision-making, and social psychology literature, Gebauer (2008) presents a framework for repositioning pharmacies as healthcare service providers in the healthcare service supply chain. Zheng *et al.* (2006) showed that making a strategic case for healthcare supply chain e-adoption is a complex process, depending on different factors, such as perceived benefits and risks, stakeholder motivation, equitable cost and benefit allocations, influential functions and individuals. Djellal and Gallouj (2005) made a framework that analysed hospital output (at the organisational, intra-organisational or inter-organisational levels), which made it possible to capture the multiple innovations encountered in hospitals. Innovation is not a particular function's exclusive preserve. Fernie and Rees (1995) summarise research currently being carried out into public sector organization supply chain management – the National Health Service (NHS). The main research evaluates supplies service performance from three perspectives: NHS supplies managers – service providers; hospital chief executives – service purchasers; and companies supplying goods to the NHS.

Mays *et al.* (2009) reviewed public health organization empirical studies published between 1990 and 2007 on financing, staffing and service delivery. A summary is provided of what is currently known about public health delivery system attributes that influence their performance and outcomes. This review also identifies unanswered questions, highlighting areas where new research is needed.

Service-oriented supply chains

Customer order backlogs can only be managed by adjusting capacity and finished goods inventory; i.e. by adjusting the resources available such as labour and equipment. For example, information services such as mortgages (home loans, etc.), insurance policies and some other customer services (automobile, healthcare, etc.) also come under service-oriented supply chains, since the work process starts only when an order is placed with the provider. Furthermore, their supply chains often include multiple backlogs, as one-stage hands work to another. Many workforce services including consulting professional services, home healthcare etc., possess similar process structures. As these supply chains typify the service industry they are called "service-oriented" supply chains. However, it is important that such supply chains are not limited to the service sector. For example, products manufactured by equipment manufacturers, are similar to services, because product manufacturing, only starts after a customer order is received, by the manufacturer. Furthermore, recent manufacturing, information technology advances after stiff competition owing to electronic commerce, many industries are choosing to hold no finished goods in their supply chains.

The widely adopted Japanese management practices came to be known as lean production. In time, the abstractions behind lean production spread to logistics and from there to military, construction and service industries. As it turns out, lean thinking is universal and has been applied successfully across many disciplines. On the other hand, some service industry supply chains such as fast foods are essentially supply chains more similar to inventory supply chains like automobile production than typical information or consulting agencies. While insights from the literature on finished goods inventory management are directly applicable to some service industries, they are able to generalize less to more typical service-oriented supply chain that consists of a backlog network.

In a service-oriented supply chain processing, flow time determines customer lead time, owing to customization inherent in many services (Fitzsimmons and Fitzsimmons, 1998) forcing most if not all product/service preparation to occur after the customer order is initially received. In contrast, in inventory supply chains, delivery time from the final stage in the supply determines the end customer lead times, assuming no stock outs (situations where demand for an item cannot be fulfilled from the current (on hand) inventory).

Typically, a supply chain deals with three flows: physical product; information; and financial flow. In most cases, the supply chain design is primarily driven by physical product flow requirements, associated constraints, and opportunities. The healthcare sector is different because financial and information flows play a critical supply chain design decision role (Singh *et al.*, 2006).

System dynamics modelling

According to Homer and Hirsch (2006), modeling system dynamics is well suited to address the complexity that characterizes many public health issues. The system dynamics approach involves developing computer simulation models that portray accumulation and feedback, which may be tested systematically to find effective policies for overcoming policy resistance. System dynamics modeling chronic disease prevention seeks to incorporate all the basic elements of a modern ecological approach, including disease outcomes, health and risk behaviors, environmental factors and health-related resources and delivery systems. System dynamics shows promise for modeling multiple interacting diseases and risks, delivery system interactions, diseased populations and national and state policy.

Lane *et al.* (2003) describe building a simulation model for understand patient waiting times in an accident and emergency department. The purpose was to explore issues that arise when clients, in this case healthcare professionals, are involved in model building. The article focuses on general themes that can be discovered running through the process. These offer some tentative insights into client involvement in system dynamics modeling, in particular its health care application.

The professional field, known as system dynamics, has been developing for the last 53 years, and now has a worldwide, and growing membership. System dynamics combines the theory, methods, and philosophy needed to analyze, not only, management systems, but, also environmental change, politics, economic behavior, medicine, engineering, and other fields. System dynamics provides a common foundation that can be applied wherever we want to understand and influence how things change through time. The system dynamics process starts from a problem to be solved – a situation that needs to be better understood, or an undesirable behavior for correction or avoidance. The first step is to tap the information wealth that people possess. Their mental database is a rich information source about the system, the information available at different points in a system and about the policies followed in decision-making. Management and social science personnel have in the past unduly restricted themselves to measured data and have neglected the far richer and more informative information that exists in the knowledge and experience of those in the active, working world. System dynamics uses concepts drawn from feedback control to organize available information into computer simulation models. A computer as a simulator, acting out people's roles in the real system, reveals the system's behavioral implications described in the model. The first articles based on this work appeared in the Harvard Business Review (Forrester, 1958). From over three decades in system dynamics modeling came useful guides for working toward a better understanding of the world around us. According to Lane *et al.* (2000, p. 518):

> Accident and Emergency (A&E) units provide a route for patients requiring urgent admission to acute hospitals. Public concern over long waiting times for admissions motivated their study, whose aim was to explore the factors contributing to delays. The article discusses formulating and calibrating a system dynamics model of the interaction of demand pattern, A&E resource deployment, other hospital processes and bed numbers; and model policy analysis runs, which vary several parameters. Two significant findings have policy implications. One is that while some delays to patients are unavoidable, reductions can be achieved by selective resources augmentation relating to the A&E unit. The second is that reductions in bed numbers do not increase waiting times for emergency admissions, their effect instead increases cancelled admissions for elective surgery. This suggests that basing A&E policy solely on any single criterion will merely succeed in transferring the effects of a resource deficit to a different patient group.

Healthcare service scenario in the region

The following data pertain to the healthcare service provided by a prominent hospital in the North-Eastern Uttar Pradesh, India. According to hospital records (Kumar, 2008), the hospital has 917 beds (750 beds for modern medicine, 127 beds for Ayurveda (alternative medicine) and 42 private beds). Annual admissions total 30,000 patients. The hospital witnesses a daily turnout around 1,700 (including the Ayurvedic department) outpatients coming from far-off places such as Bihar, Jharkhand, Chattisgarh, Madhya Pradesh and Nepal besides over one and half dozen North Eastern Uttar Pradesh districts. Patient turnout is around 530,000 annually and bed occupancy is approximately 95 percent. Surgical operations are 30,000 annually, which include Ayurvedic surgical operations. The hospital employs more than 1,000 staff and the surgical operations in a year include 55 percent minor and 45 percent major. Its state-of-the-art-facilities and super-specialty services include:

- out-patient department and emergency services;
- intensive care unit and cardiac care unit;
- operating theatre and referral services;
- round the clock operational blood bank;
- kidney transplant unit;
- computed tomography (CT) and whole body scanning facility; and
- radiotherapy unit.

Model details

We develop a system dynamics simulation model to analyze typical service-oriented supply chain dynamic behaviour, which consists of three service stages in sequence. The model is termed the base model, as subsequent models are alternatives. An order is complete only when the customer gets the service after all three stages. Each service-oriented supply chain stage contains no finished goods inventory, rather only customer order backlogs and (in subsequent stages) orders from previous stages. The model is developed and simulated using STELLA 5.0 software (Peterson and Richmond, 1996). Wolstenhome (1990) devised a checklist that includes dimensional analyses to ensure consistency; asking if all factors considered important are included in the model; ensuring the boundary assumptions are consistent with real-world situations, etc. These checks all have direct equivalence with hardware systems modeling. Model simulation time is 125 days and the increment time is taken as one day. Model simulation, using Euler's method (2001), is a simplified healthcare system. The model's first stage is depicted in Figure 1 and each application passes through three stages:

(1) *Registration and categorization*: filling registration applications for consulting appropriate specialist medical officer.

(2) *Consultation*: meeting the doctor and explaining the problem.

(3) *Testing and treatment*: based on test results and patient examination.

All model stages operate identically, so describing a single stage is sufficient. As the applications for medical checks arrive they accumulate in the processing backlog. Each time period, depending on application backlog and target capacity, is set by deciding to

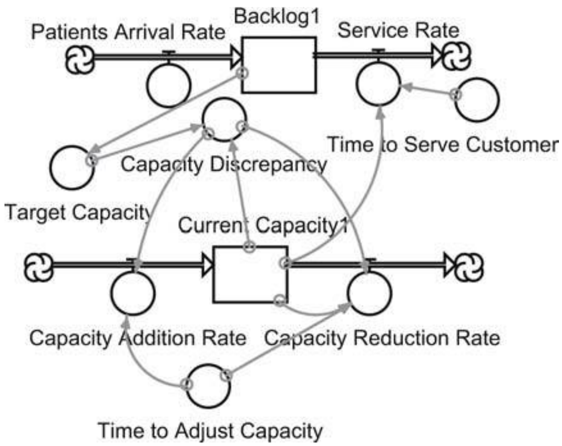

Figure 1.
First stage in the healthcare supply chain model

adjust service capacity. However, it takes time to actually find, interview and hire or, conversely, give notice and release employees, so actual capacity will lag target by an average time required to adjust the capacity. Capacity is expressed as the number of daily applications that can be processed. It cannot be negative; furthermore it cannot fall below a certain level, but there exists no upper limit on any stage's capacity. Capacity can be added only in whole numbers and no fractional capacity can be added or reduced, as there is no meaning in adding or reducing fractional numbers of persons providing services. It is assumed that capacity is planned only at the week's end or beginning, each stage can change its target capacity, which is restricted to be non-negative. For the simulation, time to adjust capacity is set at one working day. In essence, each stage's capacity will move one gap unit from its current value toward its target each day. On average in a stationary system, this will translate into an average one-day lag in capacity adjustment.

After the patient's application for healthcare is processed at the registration counter he or she will join the second stage – the patient backlog waiting for consultation. Similarly, after second stage processing, s/he will join the third stage backlog. The patient's arrival is non-stationary that takes five simulation time units (one day). The capacity is modelled as a level function with two rates, capacity addition and capacity reduction, determining capacity value at any point. Furthermore, it is assumed that there can be any number of backlogs at any stage; that is, no backlog number upper limit exists at any stage. Time for adding and reducing capacity at each stage are assumed to be equal.

Model values are chosen so that the system shows a steady operation state for a customer order value equal to 1,700 daily applications. A step-rise in customer orders (application arrival rate, AAR) is then considered to obtain the system's dynamic behaviour. That means there is a five application increase – 1,750 applications during the next one-day time period. This is achieved by considering initial application arrival rates (1700 + STEP (5, 1)) units per day. Initially, there is equal number of backlogs at each stage – equal to 900 applications: AAR = 1700 + STEP (5, 1)

Capacity is expressed as the number of applications that can be serviced each day. The initial daily capacity value is taken as 1,700 applications. Stage completion or service rate, therefore, depends on both capacity and backlog. Additionally, there is a delay (assumed to be 144 minutes) in processing an application. Figure 2 depicts application backlogs over time.

Measuring the bullwhip effect

Many authors use the variance ratio as a bullwhip effect measure (Chen *et al.*, 2000; Disney and Towill, 2003). Taking a cue from their work, we define the bullwhip effect as the service rate and patient arrival rate standard deviation ratio. In order to compute standard deviations, supplementary variables are considered. The variables related to bullwhip measure are depicted in Figure 3 and the corresponding bullwhip measure characteristics in Figure 4.

The application arrival rate is accumulated in a level variable backlog 1. The square of deviations is calculated as: Devsquare1 = (AAR-SR1)*(AAR-SR1). Where AAR is

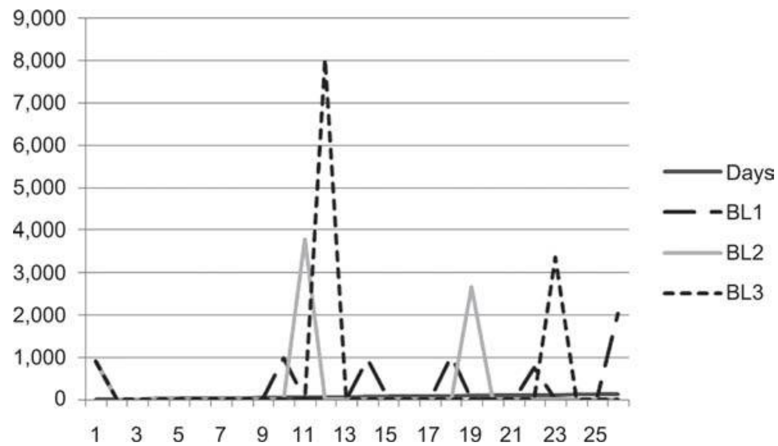

Figure 2.
Application backlog with time variations

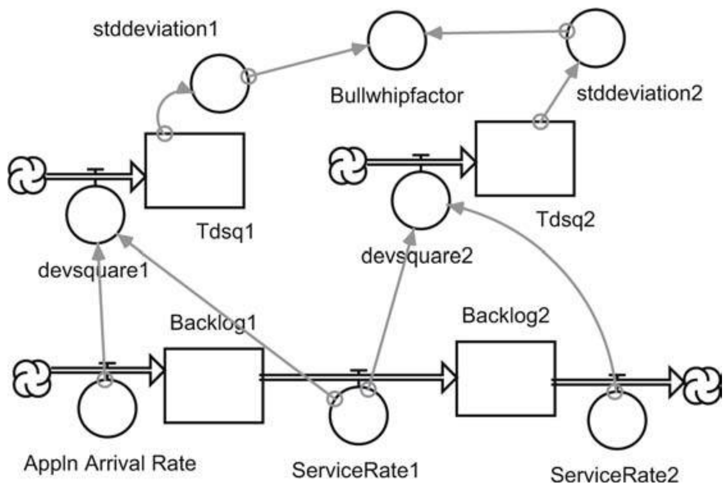

Figure 3.
Bullwhip measure flow diagram

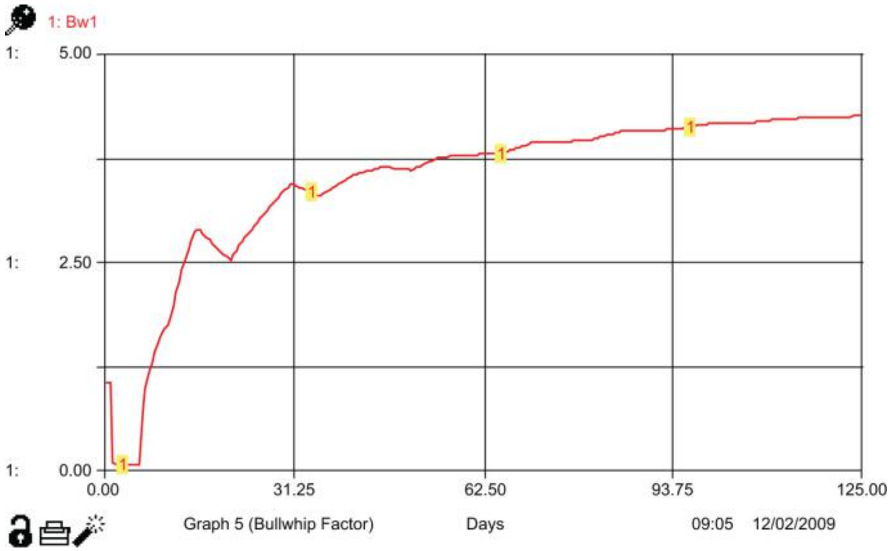

Figure 4. Bullwhip measure characteristics

application arrival rate and SR1 is service rate at stage1. The square of deviations Devsquare1 is accumulated in a level variable denoted as TDSQ1. The standard deviation is denoted by a variable Stddeviation1, which is computed as the ratio of TDSQ1 and DT square root. Thus: Stddeviation1 = SQRT (Tdsq1/DT). The variables in the other stages are also calculated as in the stage 1. The bullwhip effect measure is the standard deviation ratio: Bullwhip factor = Stddeviation2/Stddeviation1.

Reducing service and capacity delays

The service process involves some delay. Similarly, adding or reducing service capacity also involves delay, which cannot be removed. The present policy aims to reduce delays involved in the service-oriented supply chain, including delays represented by time to serve customer (TSC) and those that involve adjusting, adding or reducing capacity denoted by time to adjust capacity (TAC) in our health service-oriented supply chain model. In the service rate equation, TSC is reduced by 25 percent. Similarly time to adjust capacity can also be reduced. The new value is: $TSC_n = TSC \times 0.75$. Where "TSC_n" denote new TSC. Other variables remain the same as in the base run policy. Figure 5 depicts application backlog variation characteristics in the health service oriented supply chain model with a policy of reducing service and capacity delays. Application backlog values vary from: minimum value equal to zero to a maximum value equal to 2,725 applications at stage one; minimum value equal to zero to 3,094 applications at stage two; minimum value equal to zero to 5,183 applications at stage three over the simulation time period. As can be seen, there is a large decrease in application backlog value variations for the third stage and a slight decrease in the maximum values for stage two. Compared with the system base model, similar values were zero to 2,031 applications for stage one, zero to 3,925 applications for stage two and zero to 8,238 applications for stage three.

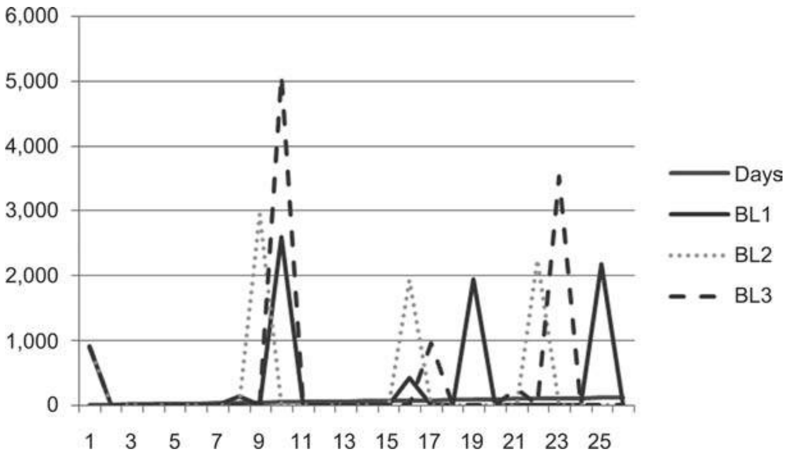

Figure 5. Backlog model with reduced delays

Table I. Policy comparisons

No.	Policy	Percentage reduction	Total cost (rupees)	Bullwhip factor
1	Base model	Nil	17,975	2.25
2	Service and capacity adjustment delays	25 percent reduction	17,100	1.93
		50 percent reduction	14,030	1.84
		75 percent reduction	8,505	1.69

The base model is compared with a 25, 50 and 75 percent reduction in service and capacity adjustment delays. The corresponding bullwhip measure values and the capacity adjustment total cost are shown in the Table I.

Conclusions and recommendations

Bullwhip like effects can be observed. A small (five application) step increase to the usual 1,700 applications amplifies the variability in the backlogs at consecutive stages like stage one, stage two and stage three respectively. Reducing capacity and service delays gives better results. Even if there is a 25 percent reduction in service and capacity adjustment delays, the bullwhip effect is considerably reduced and cost savings are significant. Scope for future work includes extending the study to service-oriented supply chains with parallel processing; i.e. having more than one stage to perform a similar operation. Specific case studies can be developed to reveal factors relevant to some particular service-oriented supply chains.

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