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BAHÇEŞEHİR ÜNİVERSİTESİ

IMPACT OF INFORMATION DISTORTION UNDER SERVICE SUPPLY CHAIN MANAGEMENT

Master's Thesis

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INDUSTRIAL ENGINEERING

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ABBREVIATIONS

Bullwhip Effect	:	BWE
Continuous Replenishment Programs	:	CRP
Electronic Data Interchange	:	EDI
Global Supply Chain Forum	:	GSCF
Gross Domestic Product	:	GDP
Gross National Product	:	GNP
Hewlett-Packard	:	H-P
Point-of-Sale	:	POS
Service Supply Chain	:	SSC
Service Supply Chain Management	:	SSCM
Supply Chain Management	:	SCM
Supply-Chain Council	:	SCC
Supply Chain Operations Reference	:	SCOR
Vendor-Managed Inventories	:	VMI

SYMBOLS

Backlog at stage *i* on day *t*	:	$B_{i,t}$
Capacity at stage *i* on day *t*	:	$C_{i,t}$
Completion rate at stage *i* on day *t*	:	$r_{i,t}$
New application start rate	:	$r_{0,t}$
Proportion of information sharing	:	α
Service delay time	:	λ
Target capacity	:	$C^{*}_{i,t}$
Target capacity time	:	τ

1. INTRODUCTION

Over the last decade, supply chain management has been one of the highly researched topics by the academicians, and has gained quite popularity among the manufacturing companies. Recently, service companies to increase or preserve their market share have also founded out the importance of their suppliers. Under the harsh global competition, it is even more important to understand the information technology, global marketing, and the nature of services in contrast to manufacturing in order to manage service businesses successfully and achieve sustainable competitive advantage. While service sector grows, employment opportunities are shifting from manufacturing to services where supply chain for services has gained a significant attention lately. For example, the services sector has begun to dominate Turkey's economy since the late 1990s. In 1999, the services sector made up 56 percent of GDP, while manufacturing was at 29 percent and agriculture at 15 percent (http://www.nationsencyclopedia.com 2009). Despite the growth of service sectors, it is generally a well known fact that services are one of the understudied areas in the field of operations management.

With the development of service industries, some of the studies have showed us that the supply chain theory can be applicable for service industries as well. As a matter of fact, the translation of supply chain management theory available for manufacturing is essential for service sectors, which might be called as service supply chain management. As one of the concerns raised in supply chains, information distortion problem is valid for both in manufacturing and service industries. Like in manufacturing industries, sharing demand information throughout the supply chain is a counter measure to reduce the information distortion (known also as the bullwhip effect) in service industries. However, under information sharing, it is a big problem to identify how the individual systems thinking ability of service chain participants impacts the dynamics of the total service supply chain.

The number of studies about information distortion on service supply chains is quite limited. Generally, capacity planning in service supply chains is considered as one of the main causes of the information distortion. Companies can share their capacity plans throughout the organization to eliminate the information distortion.

The Beer Game in the literature is the most famous game used to demonstrate the information distortion as well as the effect of information sharing in manufacturing supply chains. However, almost all orders in services are make-to-order. Therefore, Beer Game is not suitable for service supply chains. A similar one to Beer Game to simulate service supply chains to represent information distortion and amplification is Mortgage Service Game developed by Anderson and Morrice (2000). In this study, we analyze the several parameters used in Mortgage Service Game, such as capacity adjustment time, service delay time, information sharing and variability of application start rate, in order to observe their impact on information distortion on the four-stage services supply chain.

The remainder of the study is organized in the following manner. Section 2 contains the basics of services and service supply chains (SSC). Section 3 explains the information distortion problem both in manufacturing and services. Section 4 contains the description of the system service simulation based on Mortgage Service Game model and outlines experimental design used in the analysis. Section 5 presents the results of the analysis. The study concludes with section 6 where the limitations and implications of the study are discussed.

2. SERVICE SUPPLY CHAIN MANAGEMENT

Contrary to Supply Chain Management *(SCM)*, Service Supply Chain Management (SSCM) is relatively new and less studied area in the literature. Nowadays, with the increasing attention to service industry, there are some studies underlying the similarities and differences between SCM and SSCM. In this section, services and their basic characteristics will be reviewed, and the frameworks for service supply chains will be discussed.

2.1 SERVICES

In the last decade, services have dramatically become an important force in the nations' economies. Ellram et al. (2004) highlighted that services in the United States have gained importance as manufacturing became "hollowed out" in the 1980s and 1990s due to outsourcing to Asia, Mexico, South America and Eastern Europe.

Turkey's economy has been able to supply a broad range of goods and services since the early 1950s. Since then, the mix of domestic production has shifted from agriculture to manufacturing, and then to services. In the early 1950s, agriculture made up a little fewer than 50 percent of gross domestic product (GDP), while the manufacturing sector's share was about 20 percent. In the 1970s, with the government's continued emphasis on industrialization, manufacturing caught up with agriculture for the first time and surpassed it. This trend continued until the 1980s. With the economic reforms of the 1980s, the economic shift accelerated as all sectors exhibited strong growth, though both manufacturing and services grew much more rapidly. By the late 1990s, the services sector began to dominate the domestic economy: in 1999, the services sector made up 56 percent of GDP, while manufacturing was at 29 percent and agriculture at 15 percent. However, all 3 remain vital to the Turkish economy (http://www.nationsencyclopedia.com 2009). Additionally, lately Central Intelligence Agency (CIA) (n.d.) gave us the percentage contribution of *agriculture*, *industry*, and *services* to total GDP in Turkey (2008 estimated) as 8.5%, 28.6% and 62.9%, respectively.

When we look at the relative contribution to gross national product (GNP) of industry, agriculture and various service-sector businesses for Turkey for 2005, in Figure 2.1, the largest share, 63%, belongs to the service sector. The industry sector has the second largest share with 26%, while the agriculture sector is third with its 11%. It is worthy to note that trade is the leading sector in services with its 21% share in the total GNP (http://www.hmtokyo.jp/econoutlook.pdf).

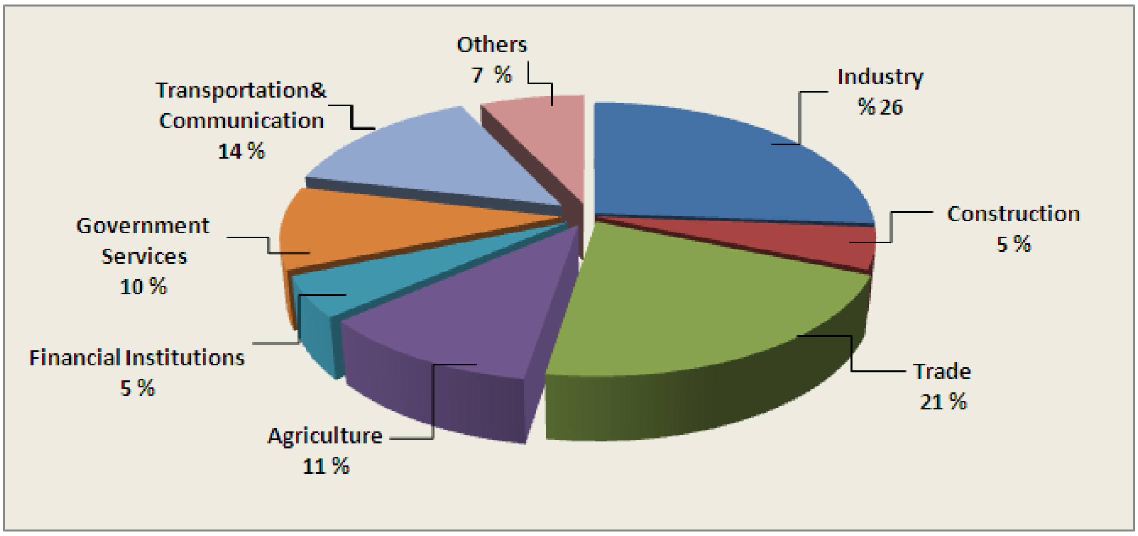

Figure 2.1 : Services sector as a percent of GNP in Turkey, 2005
Source: http://www.hmtokyo.jp/econoutlook.pdf , n.d.

Service companies, especially small businesses want to get a bigger share from increasingly competitive world market. While demands for many services are growing managing services effectively is essential for service companies. For both service and manufacturing companies, communication and information sharing are vital not only within the company but also among the companies. As a matter of fact, supply chain management is important for not only manufacturing firms but also for service firms. It would not be wrong to call service supply chain in service industries similar to SCM in manufacturing.

2.2 CHARACTERISTICS OF SERVICES

By nature, service operations are different in a practice from manufacturing operations due to the characteristics of services. In order to understand and manage service operations effectively and efficiently, these unique characteristics should be deeply examined and known well. Services are considered to be more intangible, heterogeneous, perishable, and inseparable from their source of production (simultaneity).

Intangibility: Services are intangible. Intangibility is often cited as one of the fundamental differences between goods and services since a service cannot be seen, touched or tasted in the same manner as a manufactured product (Fitzsimmons and Fitzsimmons 2004).

Heterogeneity: Services are heterogeneous. Fitzsimmons and Fitzsimmons (2004) highlighted the combination of the intangible nature of services and the customer as a participant in the service delivery system results in variation of service from customer to customer. Heterogeneity means that it is almost difficult to standardize services. Because every customer wants different output of service while taking it, related with his mood, experiences, perceptions and even the weather conditions of that day.

Simultaneity: Services are simultaneously produced and consumed. Some of goods are produced without the attraction with the customers and then shipped, sold, and consumed where the production and consumption stage are separate. However, generally services are sold first and then produced and consumed simultaneously. The inseparability of production and consumption, often called simultaneity, makes the production process exposed for customer examination and influence (Nie and Kellog 1999).

Perish ability: Services are perishable. Perish ability makes difficult to manage demand, capacity utilization, production planning, and personnel scheduling. For examples, an empty airline seat, an unoccupied hospital or hotel room, theater or cinema tickets or an hour without a patient in the day of dentist (Fitzsimmons and Fitzsimmons 2004). Services must be consumed when they are available; otherwise there is no way to store them for using in another days. It means that unused capacity is lost forever (Fitzsimmons and Fitzsimmons 2004).

2.3 SERVICE SUPPLY CHAINS

Service sector is growing and employment opportunities are shifting from manufacturing toward services so supply chain for services has received much more attention in nowadays. However, there have not been enough studies on service supply chain. As a matter of fact, the general definition of service supply chain has not been given yet. The concept of service supply chain has been researched in several aspects, especially by foreign scholars. Many studies were conducted on this subject in recent years. Fitzsimmons et al. (1999) stated that "Service Supply Chain Management is concerned with the planning and management of activities from support functions to the delivery of end-user services." Anderson and Morrice (2000) developed a four-stage service game (which is called as mortgage service game) in order to find out if there is any impact of "bullwhip effect" in "Service-Oriented Supply Chain" with managing entity product in the service industry. Cook et al. (2002) declared that "the discernments between manufacturing and services industry is not always as "white and black", there is sometimes "a gray area" and a mixed industry that include both the manufacturing and service sectors. In order to link these sectors an effective supply chain is crucial." Ellram et al. (2004) studied on the professional service supply chain and proposed that a new service supply chain model based on the most appropriate supply chain framework, including six processes: capacity management, demand management, customer relationship management, supplier relationship management, service delivery management and cash flow management. Baltacioglu et al. (2007) proposed that "The service supply chain is the network of suppliers, service providers, consumers and other supporting units that performs the functions of transaction of resources required to produce services; transformation of these resources into supporting and core services; and delivery of these services to customers." Liu et al. (2008) marked that "Service supply Chain *(SSC)* is a service-network that reorganizes different service entities in order to satisfy customers' require by using modem management technology to break down and rebuild a system which considers customers' demands as starting point and takes a complex service or an Integrated Service Package as a series of process in service when the service-industries are developed to some extent." Following the definitions of Service Supply Chain in these studies, yet the definition of SSC is still not clear and unique.

2.4 FRAMEWORKS FOR SERVICE SUPPLY CHAINS

There are a few numbers of studies in literature about applying a new model for service supply chain (Sampson 2000; Ellram et al. 2004; Boyer and Hult 2005). With respect to these limited studies related with the subject, it is obvious that there is an unknown area that hides in the concept of the service supply chain.

Ellram et al. (2004) made the most remarkable study related with a new model for service supply chain in literature so far. They propose a supply chain framework appropriate for a service supply chain by comparing and contrasting three well-known product-based manufacturing models — Global Supply Chain Forum framework, SCOR and Hewlett-Packard's supply chain management model — and they conclude with a call for more service supply chain-related research.

Hewleet-Packard Model: This model proposed by Lee and Billington (1995) and employed by Hewlett-Packard (H-P). It includes that suppliers, factories and customers are linked in the flow of goods in an uncertain environment, and that multiple inventory stocking locations provide the buffer for that uncertainty. For Hewlett-Packard Model, inventory is an essential point in every phase because there is uncertainty. Uncertainty makes managing a supply chain difficult (Ellram et al. 2004). This model supports for Services SC because it considers buffers against uncertainty and utilizes capacity levels and flexibility versus inventory. However, services cannot be inventoried and this model cannot easily address the difference in quality of services (Ellram et al. 2004).

The SCOR Model: This model is the supply chain operations reference model (SCOR) developed by the Supply-Chain Council (SCC). Harrison and Van Hoek (2008) gave a definition that the supply chain operations reference model (SCOR) is founded on five distinct management processes: plan, source, make, deliver, and return within an integrated planning framework that encompasses all of the integrations in the chain. These areas repeat again and again along the supply chain. This model supports for

Services SC because also services are process driven. However, the separate processes of make, deliver and return do not fit services and services do not have a return cycle (Ellram et al. 2004).

The GSCF Framework: The global supply chain forum framework (GSCF) depicted by Croxton et al. (2001) is built up based on Porter's value chain model (1985). The GSCF identified eight key processes that need to be implemented within across firms in the supply chain; customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, procurement, product development and commercialization and returns. This model supports for Services SC because participants from the beginning to end of the chain are included encompassing suppliers as well as customers and coordination of information and integration improve flow of the chain. Although services do not have a return cycle, this model fits the product and component of flow of goods. This model can be applied to the service supply chain (Ellram et al. 2004).

Ellram et al (2004) modified the supply chain definition for professional services as follow: *Service supply chain management is the management of information, processes, capacity, service performance and funds from the earliest supplier to the ultimate customer*. Ellram et al. (2004) proposed a model for studying service chains, which is based on the GSCF model of supply chain management This new model includes six key process; capacity management, demand management, customer relationship management, supplier relationship management, service delivery management and cash flow management.

3. INFORMATION DISTORTION

Information distortion also known as Bullwhip, Forrester or whiplash effect is one of the key areas of research in supply chain management applications. It represents the phenomenon where orders to supplier tend to have larger variance than sales to the buyer, and customer demand is distorted (Bayraktar et al. 2008). Lee et al. (1997) was one of the first studies highlighted the impact of information distortion recently. This phenomenon had appeared in manufacturing sectors as well as services sectors.

3.1 INFORMATION DISTORTION IN MANUFACTURING

Moon and Kim (2005) highlighted that the supply chain is a series of processes, ranging from raw material suppliers to end customers, which includes information, cash, and material as core flows. In the case of information and material flows, the supply chain always has dynamic characteristics. In other words, information and material flows change with time and the dynamics are represented as information distortion. The information distortion is a phenomenon whereby a small change in demand of end customers is amplified as it goes upstream.

In a supply chain for a typical consumer product, even when consumer sales do not seem to vary much, there is pronounced variability in the retailers' orders to the wholesalers. Orders to the manufacturer and the manufacturers' supplier spike even more. To solve the problem of distorted information, companies need to first understand what creates the bullwhip effect so they can counteract it (Lee et al. 1997).

Numerous researchers have studied a lot either to eliminate or to understand the underlying reasons of the bullwhip effect for several decades (Lee et al. 1997; Anderson et al. 2000; Chen et al. 2000a,b; Moon and Kim 2005; Bayraktar et al. 2008). Understanding the causes helps managers design and develop strategies to reduce it (Lee et al. 1997). The causes and counter measures of information distortion (bullwhip effect) are shown below:

Demand forecast updating: Ordinarily, every company in a supply chain forecasts its demand myopically--that is by looking at the past demands they have faced from their own direct customers. Since each upstream chain member sees fluctuations in demand caused by the bullwhip effect from downstream, that member orders accordingly, creating further swings for the upstream suppliers. This occurs even when the ultimate demand is relatively stable. One obvious way to counteract this forecast effect is for all members of a supply chain to use the same basic demand data coming from the furthest downstream points. Technologies such as point-of-sale (POS) data collection, electronic data interchange (EDI), vendor-managed inventories (VMI), as well as lead-time reduction can all help to reduce the problem (Hill 2003).

Order batching: Companies placing orders on upstream suppliers usually do so periodically, ordering a batch of an item to last several days or weeks, thus reducing transportation costs or transaction costs or both. These tactics contribute to larger demand fluctuations further up the chain. Companies can use electronic data interchange (EDI) to reduce the transaction costs form orders by one member and other members of supply chain. Also they can reduce transaction costs through various forms of electronic ordering, offering discounts for mixed-load ordering (to reduce the demand for solid loads of one product), and the use of third party logistics providers to economically combine many small replenishments for many suppliers or to customers (Hill 2003).

Price fluctuation: Frequent price changes--both up and down--lead buyers to purchase large quantities when prices are low, and avoid buying when prices are high. A common practice in the grocery industry, this forward buying creates havoc upstream in the supply chain. The answer here is for sellers to stabilize prices (e.g. “everyday low prices”). Activity-based costing systems that highlight the excessive costs in the supply chain caused by price fluctuations and forward buying also can help provide the incentive for the entire chain to operate with relatively stable prices (Hill 2003). From an operational perspective, practices such as continuous replenishment programs (CRP) together with a rationalized wholesale pricing policy can help to control retailers’ tactics, such as diversion (Lee et al. 1997).

Rationing and shortage gaming: Cyclical industries face alternating periods of oversupply and undersupply. When buyers know that a shortage is imminent and rationing will occur, they will often increase the size of their orders to insure they get the amounts they really need (Hill 2003). To counteract this behavior, Lee et al. (1997) advocate allocation of demand among customers based on past usage, not on present orders. Furthermore, they encourage more open sharing of sales, capacity, and inventory data so that buyers are not surprised by shortages.

In order to make an exact definition of information distortion in services, it is important to highlight the differences between services and manufacturing based on the nature of each one. In service supply chains, human labor is essential and capacity is a vital issue where the inventory is important in manufacturing. These issues causes root causes and counter measures of information distortion in services different from in manufacturing.

3.2 INFORMATION DISTORTION IN SERVICES

Even though there are many studies related with information distortion in manufacturing industries, unfortunately, there are just a few studies related with this phenomenon in services.

One of these studies on the information distortion in service settings is the Mortgage Service Game by Anderson and Morrice (2000). This game was developed to study decision-making in service-oriented supply chains which consists four process steps: initial processing, credit checking, surveying and title checking. According to findings from classroom experiments with mortgage game, Anderson and Morrice (2000) found evidence about the presence of amplification effects. In order to measure amplification effects, interestingly they used backlog instead of finished goods inventories. Each process can only control its backlog by managing its capacity that is the number of employees. Anderson and Morrice (2000) concluded that sharing demand information throughout the supply chain is a perfect measure in order to counter amplification effects.

The other is related with the root causes of “bullwhip effect” on one of service industries (Akkermans and Vos 2000). They mentioned on a case study from the telecommunication industry, aiming to analyze relevant root causes and associated counter-measures of the amplification phenomenon in service supply chains in order to improve the quality and flexibility of service processes because of that their study has a broader perspective rather than the study of Anderson and Morrice (2000). Their study is very similar to the study of Mortgage Service Supply Chain (Anderson and Morrice 2000). There are also four separate stages; selling, provisioning, install and billing. Each stage has a finite capacity, derived from number of staff working in the stage, their skill level and their working hours. With case findings, Akkermans and Vos (2000) confirmed the occurrence of upstream amplification of workload in the service supply chain, workload being a more appropriate measure for amplification effects in service supply chains than inventory levels. According to their case results, there weren't be found all root causes of "bullwhip effect" in manufacturing industries; batch ordering and shortage-gaming (Akkermans and Vos 2000).

3.2.1 Root-Causes of Information Distortion in Services

Order batching: Of the four generic root causes of amplification effects, batch ordering can not apply in the service supply chains where the intangible nature of services is because there is no way to hold inventories and also the delivery of services is essentially make-to-(customer)order. It means that output of services is simultaneously produced and consumed. In other way to say, there is impossible to use finished goods inventories as a buffer against demand fluctuations (Akkermans and Vos 2000). Because of these two natures of services, order batching is not relevant as a root cause of amplification effects in service operations.

Shortage gaming: The other root cause of amplification effects, shortage gaming may apply in the service supply chains. For example, based on the findings of study, Akkermans and Vos (2000) highlighted that customers requesting a second line certainly do not ask for an extra line to make sure they will at least get one installed. It means that according to them, shortage gaming can not apply. Although there is no clear examples of shortage gaming in service operations, but customers may apply rationing practices when buying certain services. For example, in periods of anticipated capacity shortages for services like hotel rooms or airline seats, customers may place orders with various suppliers to increase to likelihood of satisfying their demand. In such cases, shortage gaming can be relevant as a root cause of amplification effects in service operations.

Demand signaling: Demand signaling, unlikely, can be a major root cause of amplification effects in service environments for a similar reason as batch ordering's reasons which are the natures of services: intangible and simultaneity. Lee et al. (1997a, p. 556) already noted that "the direct marketing channel design is not subject to the bullwhip effect created by demand signal processing by the distribution channel"(Akkermans and Vos 2000). This direct interaction with customers is common for service operations. However, that amplification effects might be expected in the back office processes of service companies. Chase (1996) highlighted that this is in line with Chase's point of view that the back office parts of service operations function very much like a factory (Akkermans and Vos 2000).

Price fluctuations: Price fluctuations may also apply in service supply chains. In fact, Chase (1996) highlighted yield management is an established practice in many service environments to use differential pricing to allocate time-dependent in order to maximize total revenues. In essence, services are offered at discount prices to attract customers in anticipation of periods of reduced demand (Akkermans and Vos 2000).

3.2.2 Counter-Measures of Information Distortion in Services

Capacity reservations: Advance capacity reservations might mean making sure that sufficient employee would be present to deal with sudden increases in customer demand because most of the service operations, capacity means "employees", but not all the time. For example, Akkermans and Vos (2000) highlighted that with unexpected events such as extreme weather conditions or computer breakdowns this is practically impossible. By working overtime and holiday planning some capacity adjustments can be made. Moreover, if hiring and training skilled staff in all stages of service supply chain is a process that takes time, far longer than the few weeks or months that this additional capacity is needed. For example, in Mortgage Service Game, it can be only changed "capacity" that means "the number of employees" in order to respond demand fluctuations. And if these skills are fairly unique for a particular operation as each stage in Mortgage Service Game, capacity might not readily be reserved from other stages, either; because as it is mentioned before, every stage or every operation has its own capacity.

Information sharing: The biggest main reason of bullwhip effect is non-information sharing. For instance, Anderson and Morrice (2000) concluded that if all four stages share their capacity and backlog information, like that the amplification effects can decrease dramatically. Akkermans and Vos (2000) mentioned that sales forecast data are being shared with operations management. Information sharing indeed leads to somewhat better coordination. Akkermans and Vos (2000) gave example about information sharing from the telecom company in their case study: "The timing of sales campaigns could be tuned in such a way that they would not coincide with seasonal demand peaks or holiday periods for staff. Still, given the limited opportunities to make processing capacity more flexible in the short term, this counter-measure could only yield modest benefits in this case."

Strict quality controls: In order to counter measure root causes of amplifications, it is essentially important to get high quality controls on the workers trained to be capable of providing high-quality services to customers. This counter measure that Akkermans and Vos (2000) suggested is additional one. In their study, their respondents had mentioned the interactions of quality and workload as a key driver behind amplification effects in their service supply chain. Therefore, they tried to understand the potential impact of strict quality management on the different stages of their "establish customer service" process. During their research, they saw that quality management was not top on the list of management priorities. Akkermans and Vos (2000) gave examples about strict quality controls from the telecom company in their case study: "One initiative, for example, was in the sales department. In that department, the order-capturing system was an outdated mainframe-application, the sales staff was insufficiently trained in dealing with new products and performance incentives were misaligned. Instead of rewarding an error-free order capturing process, sales agents were merely evaluated on the revenues they realized. In evaluating the potential of these and other local quality improvements, we used our system dynamics simulation model."

Stabilize prices (Every-day-low-prices): As manufacturing supply chain, it is one of important counter measures is "ever-day-low-prices". Akkermans and Vos (2000) highlighted that according to most of the operations people that they interviewed, refraining from sales campaigns might have eliminated the observed amplification effects. This would appear to hold at least for more complexes.

4. SIMULATING A SERVICE SUPPLY CHAIN

“Beer Game” is one of the well-known supply chain games which are used to demonstrate the information distortion (bullwhip effect) in the literature. This game allows the players to imitate the role of a retailer, wholesaler, distributor, or manufacturer in a single product distribution supply chain to manage the inventory (Anderson and Morrice 2000). The simulation helps players to gain first hand knowledge about the “bullwhip effect” (Sterman 1989b). However, this game does not fit to a service supply chain since it deals with finished goods inventory, where service supply chains do not have finished goods inventory. Anderson and Morrice (2000) has developed a supply chain game called the *Mortgage Service Game* with three main features:

1. The supply chain has multiple, potentially autonomous, players performing a sequence of operations.
2. Finished goods inventory is not an option because the product or service is essentially make-to-order.
3. Each player manages order backlog by adjusting capacity.

Like the Beer Game, they chose to model a specific application rather than a generic model. Furthermore, the mortgage service supply chain supports a realistic application that covers all three features above. The aims of this game are to see how well the participants apply the supply chain principles and how effectively they use end-user demand information to reduce backlog in order to improve their performance.

4.1 MORTGAGE SERVICE GAME

Anderson and Morrice (2000) presents a simplified mortgage approval process from application submission through approval in Mortgage Service Game. The aim of this model is to include all crucial elements of most of service supply chains rather than simulate the mortgage industry. Each mortgage application passes through four stages (Anderson and Morrice 2000):

1. *initial processing* : filling out the application with a loan officer
2. *credit checking* : confirmation of employment and review of credit history
3. *surveying* : a survey of the proposed property to check for its value, as well as any infringements upon zoning laws or neighboring properties
4. *title checking* :ensuring that the title to the property is uncontested and without liens

Anderson and Morrice (2000) explain just the survey section of the model in order to show the processes in each stage, since all the other stages operate in the same manner. As each application is checked for the credit worthiness of its applicant, the application flows from the backlog of credit checks to join the backlog of surveys (Surveying Backlog). As each application is surveyed, the application flows from the backlog of title checking (Title Checking Backlog).

In practice, the problem occurs when each stage is managed by different companies because each company controls its own individual capacity, moreover each one can see only its own backlog to make the decision and they cannot see the new application rate or other stages' backlogs. This situation causes something similar to the bullwhip effect such as it occurs in the Beer Game. Additionally, backlogs are controlled in the Mortgage Service Game, while inventories are controlled in the Beer Game.

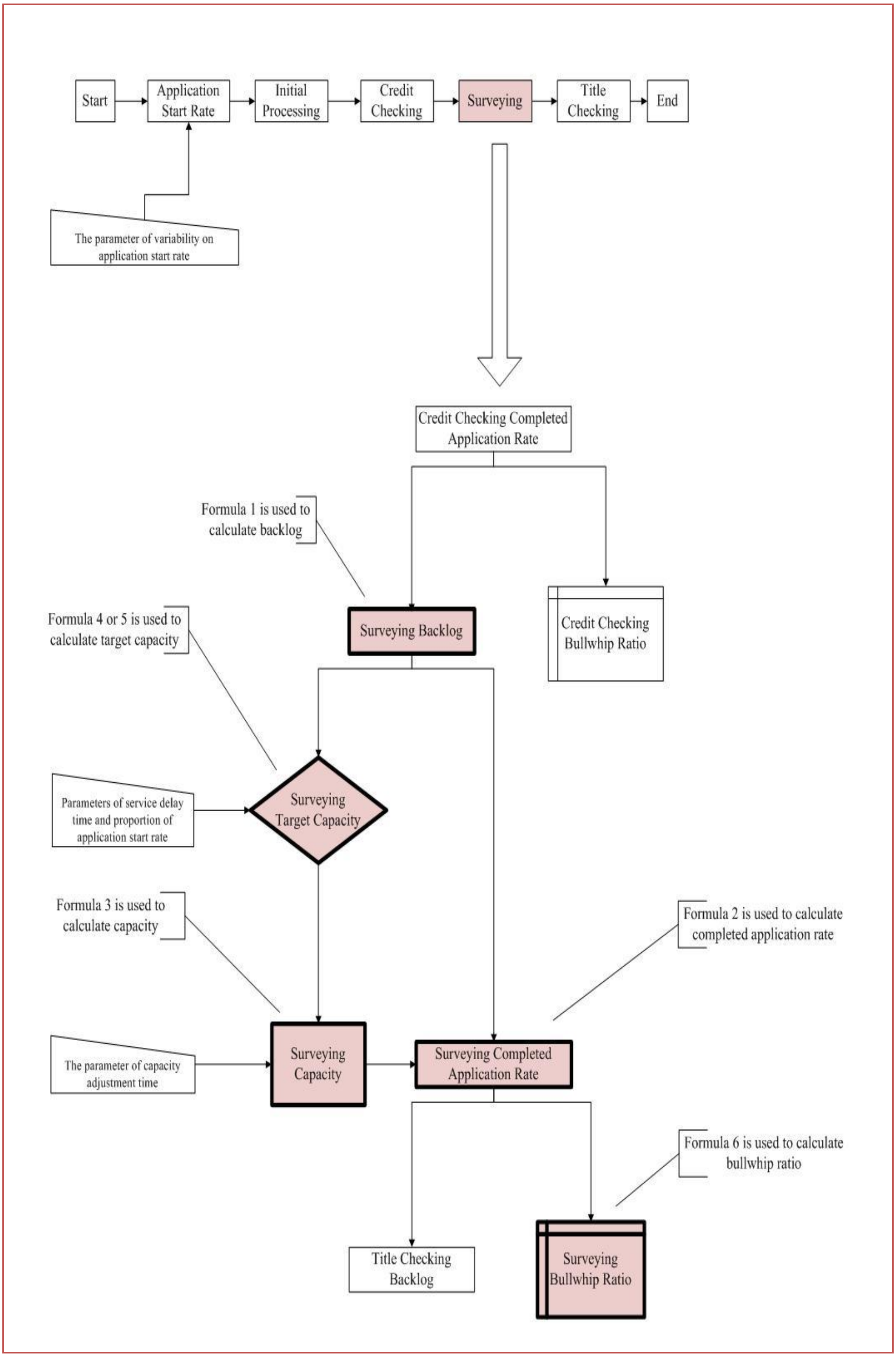

Figure 4.1 : Flowchart of simulation model

4.2 SIMULATION MODEL

There are four stages in mortgage service game; *initial processing*, *credit checking*, *surveying* and *title checking*. In each stage, players manage their own backlog by controlling their capacity which is the number of workers.

Mathematically, Anderson and Morrice (2000) describes the structure for each stage of the process as follows (Let stages 1, 2, 3, and 4 refer, respectively, to the application processing, credit checking, surveying, and title checking stages):

$$B_{i,t+1} = B_{i,t} + r_{i-1,t} - r_{i,t} \tag{1}$$

$$r_{i,t} = \min\,(C_{i,t},\, B_{i,t} + r_{i-1,t}) \tag{2}$$

where $B_{i,t}$, $C_{i,t,}$ and $r_{i,t}$ refer, respectively, to the backlog, the capacity, and the completion rate at stage i on day t. $r_{0,t}$ represents the new application start rate, which is determined exogenously. For simplicity, Anderson and Morrice (2000) assume that each employee has a productivity of one application per day. Depending on this assumption, the completion rate of applications at any stage is equal to the minimum of the backlog plus any inflow from the previous stage or the capacity. Each stage's backlog is initialized at the beginning of the game to $\lambda[r_{i,0}]$ where $\boldsymbol{\lambda}$ is a constant representing the average nominal delay required to complete a backlogged application. Each stage's capacity is initialized at $r_{i,0}$ so that the backlogging and completion rates at each stage are in balance (see Equations 3 and 4 below). At the beginning of each week (i.e., every 5 business days), each player can change its target capacity by deciding to hire or fire employees. However, in order to achieve the desired number of employees it takes time to advertise, interview, and hire employees, so Anderson and Morrice (2000) give the rate of capacity change in Equation 3.

$$C_{i,t+1} = C_{i,t} + \frac{1}{\tau}\,(C^{*}_{i,t} - C_{i,t}). \tag{3}$$

The target capacity $C^{*}_{i,t}$, set by the player is restricted to be nonnegative. The $\boldsymbol{\tau}$ parameter is called as **the capacity adjustment time**. Basically, each stage's capacity will move one percent of value of capacity adjustment time of the gap from its current value toward its target each day. If at the next begging of week the players want to change capacity before the previous target capacity adjustment is completed, the previous target will be ignored and the next day capacity will begin to adjust from its current value towards the new target. Mathematically the target capacity decision can be made as in Equation 4.

$$C^*_{i,t} = \frac{B_{i,t}}{\lambda} \qquad \text{if } (t \text{ modulo } 5) = 0$$
$$C^*_{i,t} = C^*_{i,t-1} \qquad \text{otherwise.} \tag{4}$$

Thus, each week the target capacity for each stage will be set directly proportional to the stage's current backlog $B_{i,t}$ and inversely proportional to **the service delay time λ.**

As an alternative, it is proposed another strategy called the new starts information strategy. In this strategy, in each stage capacity decisions is made based on its own backlog and the new application rate. For this new strategy, target capacity decision is made in Equation 5 which is derived from Equation 4:

$$C^*_{i,t} = \alpha r_{0,t} + (1 - \alpha)\frac{B_{i,t}}{\lambda} \qquad \text{if } (t \text{ modulo } 5) = 0$$
$$C^*_{i,t} = C^*_{i,t-1} \qquad \text{otherwise.} \tag{5}$$

where $0 \leq \alpha \leq 1$. Target capacity is determined by using the magnitude of α for determining the proportion of the application start rate or information sharing.

A four-stage service supply chain is simulated in Microsoft Excel. Simulation logic along with a flowchart is shown in Figure 4.1. The service supply chain model above is simulated for 2700 days. We also perform the simulation model by changing the (parameters) values of target capacity adjustment time τ, the nominal service delay time λ and the proportion of information sharing α. Also the variability on application start rate for each day is as a random number with uniform distribution. Finally, several combinations of these parameters are selected to perform the analysis in order to observe and see how information distortion occurs. Appendix 1 – Table A shows how to use these equations in Microsoft EXCEL for first stage where all equations are the same for other stages.

4.2.1 Generation of Application Start Rate

The system is simulated due to four different application start rate in order to show system behavior. As Anderson and Morrice (2000) suggested in their study, the first scenario was assumed that the number of applications has started at 20 per day and remained at this point until after 40 days. Then it has jumped to 27 starts per day and remained constant at 27 until the end of the game in day 2700. The other scenarios assume that the starting application rate for each day distributes according to a uniform distribution which is set in three levels: low, medium and high fluctuations denoted by U[19-21], U[18-22], U[15-25] respectively.

4.2.2 Model Verification and Validation

To verify and validate the model, two main graphics that Anderson and Morrice (2000, pp.45-46) showed in their study are tried to make by using the same strategy that they considered. It is mentioned as the first strategy in the previous section. Based on this strategy, the number of application starts at 20 until after 8 weeks and then it jumps to 27 starts per day and remains constant at 27 until end of the week 100. Additionally, the parameters of capacity adjustment time (τ), service delay time (λ) and the proportion of the application start rate (α) are 20, 10, and 0, respectively. Also, each stage begins with a backlog of 200, capacity of 20 per day and target capacity of 20 applications per day. These two graphics are shown below as Applications Processing for All Stages over Time and Stage Backlogs over Time (Figure 4.2 and Figure 4.3).

For other scenarios, the mortgage service game was simulated for 540 weeks (2700 days). The initial parameters of the simulation model were estimated by the first 54 weeks (270 days) of simulation run, which were removed later from the output analysis to eliminate the warm-up period effect. Hence, rests of data (495 weeks (2430 days)) were used for effective simulation output analysis. Additionally, 20 replications were performed for each scenario and the uniform distribution was used in the generation of a random number as the start application rate for each day.

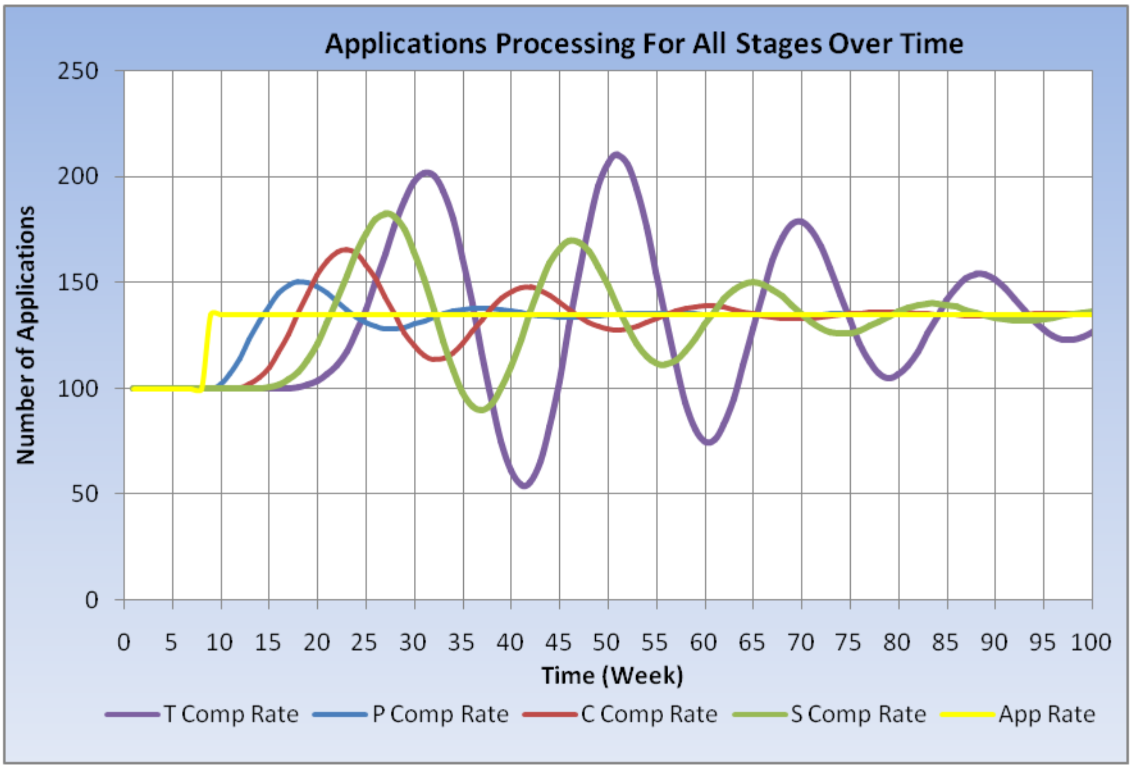

Figure 4.2 : Applications processing for all stages over time

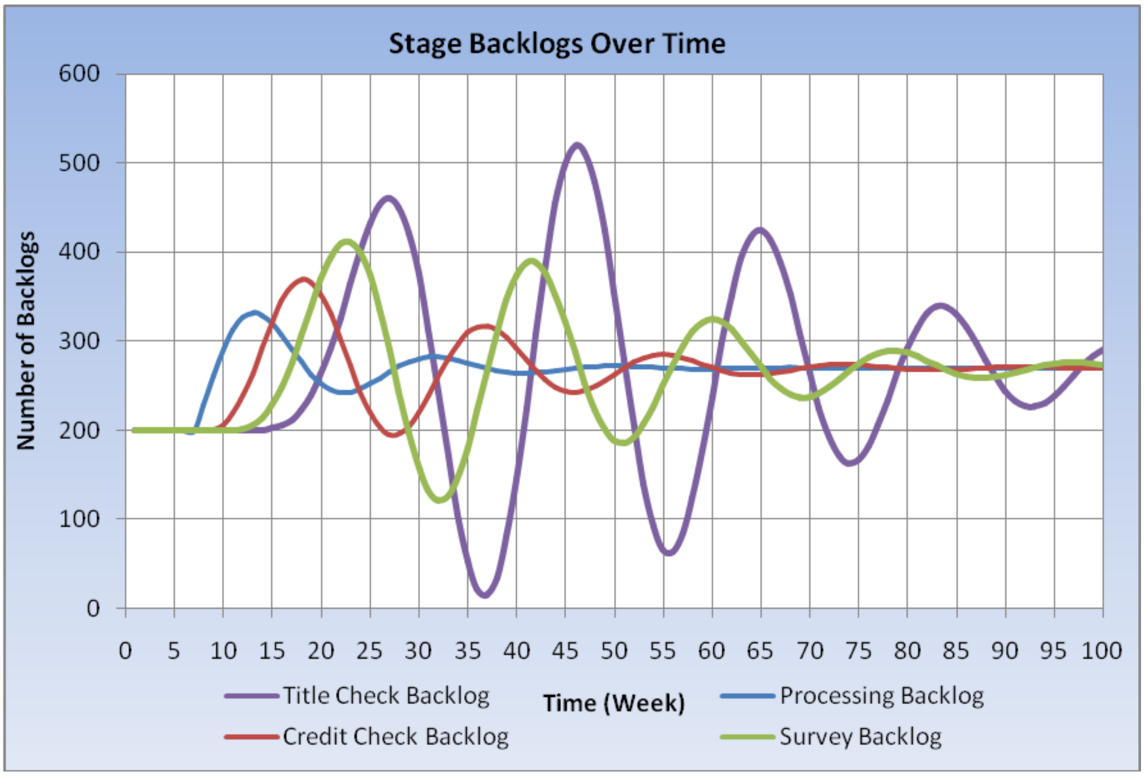

Figure 4.3 : Stage backlogs over time

4.3 EXPERIMENTAL DESIGN

The purposes of the experimental design are: (1) demonstrating time for system stabilization with respect to different capacity adjustment time, service delay time and the proportion of information sharing based on first strategy in which application start rate is changed once after 40^{th} day and it remains constant until the end of simulation, 2700 days, in other words demonstrating how long it takes to eliminate fluctuations of completion rate which occur after this variation of application start rate throughout all stages (2) analyzing the impact of capacity adjustment time, service delay time, the proportion of information sharing and also variability on application start rate on the bullwhip effect – information distortion - for a four-stage service supply chain. As three levels of variability on application start rate are mentioned, here the number of levels of these factors with their respective values is listed in Table 4.1. With three different levels for each of the three parameters and three levels of variability on application start rate, $3^4 = 81$ different scenarios are produced totally.

Table 4.1 : Independent factors of the experimental design

Independent factors	Levels		
	1	**2**	**3**
Adjustment capacity time (τ)	15 day	20 day	25 day
Service delay time (λ)	5 day	10 day	15 day
Proportion of information sharing (α)	0	0,5	1

The *bullwhip ratio* is denoted as the dependent variable of the design of experiment. Bullwhip ratio is calculated as in Equation 6. It indicates the ratio of variance of the completion rate at stage i to the variance of the application start rate in order to calculate bullwhip ratio at stage i as in Equation 6.

$$\text{Bullwhip Ratio(i)} = \frac{\text{Var(Completion Rate (i))}}{\text{Var(Application Start Rate)}} \quad (6)$$

5. RESULTS

Out of 2700 days of the simulation of the mortgage service game above, data from days 271 to 2700 for twenty replications are used for simulation output analysis. Several scenarios are analyzed by the parameters λ, τ, α, and variability on application start rate. For each scenario, the bullwhip ratio is calculated for each stage of a four-stage service supply chain. As it was mentioned in the part of “Experimental Design”, there are two main aims in this study.

5.1 SYSTEM STABILIZATION

The first aim of this study is to demonstrate time for system stabilization with respect to three different parameters; different capacity adjustment time, service delay time and proportion of information sharing based on first strategy. In other words, in this strategy, the number of application starts at 20 until after 40 days and then it jumps to 27 starts per day and remains constant at 27 until end of 500 days. This variation of application start rate makes fluctuations on completion rates at all stages. These fluctuations are amplified at every next stage. The aim is to see at which day these fluctuations on completion rate at each stage can be eliminated and all completion rates can remain constant at 27 as application start rate until the end of simulation, 2700 days. Additionally, we ignore the $\pm$0,001 deviation and accept the values like 26,999 and 27,001 as 27. Table 5.1 shows the days when system stabilizes due to our assumptions. There are $27(=3^3)$ scenarios are produced with respect to three levels of three different parameters (See Table 5.1).

By using these data, Figure 5.1 and Figure 5.2 are generated as Main effects plot for time for system stabilization and Interaction plot for time for system stabilization, respectively. Additionally, in Figure 5.1 a graphical representation of the variation of time for system stabilization with respect to capacity adjustment time, service delay time and proportion of information sharing is shown. Besides, In Figure 5.2, a graphical representation of the variation of time for system stabilization with respect to interactions of capacity adjustment time, service delay time and proportion of information sharing is shown.

Table 5.1 : Time for system stabilization with respect to three parameters

τ	λ	α	Time (day)
15	5	0	1250
15	10	0	568
15	15	0	488
20	5	0	1713
20	10	0	777
20	15	0	662
25	5	0	2154
25	10	0	1006
25	15	0	803
15	5	0,5	570
15	10	0,5	403
15	15	0,5	367
20	5	0,5	777
20	10	0,5	571
20	15	0,5	483
25	5	0,5	962
25	10	0,5	705
25	15	0,5	614
15	5	1	117
15	10	1	117
15	15	1	117
20	5	1	142
20	10	1	142
20	15	1	142
25	5	1	167
25	10	1	167
25	15	1	167

As it is simply seen in Table 5.1, the earliest days for system stabilization are achieved when the proportion of information sharing, α, is equal to 1, such as 117th day, 142th day, and 167th day. Moreover, it is seen that the parameter of service delay time, λ doesn't have any effects on system stabilization when the parameter of proportion of information sharing is equal to 1. In other words, there is totally information sharing so it is used only application start rate for setting the target capacity, not backlog and service delay time. Furthermore, among these days, the earliest one, 117th day, is seen three times when capacity adjustment time, τ is equal to 15. Similarly, the latest day for system stabilization is 2154th day in a scenario where the τ parameter has the highest value, 25; the λ parameter has the lowest value, 5 and the α parameter is equal to 0.

The graphics in Fig. 5.1 indicate that time for system stabilization is significantly influenced by capacity adjustment time, service delay time and proportion of information sharing. These graphics also show that any increase in the value of capacity adjustment time (tau) leads to stabilize system at much later time. In contrast, as service delay time (lambda) and proportion of information sharing (alpha) increase, time for system stabilization decreases.

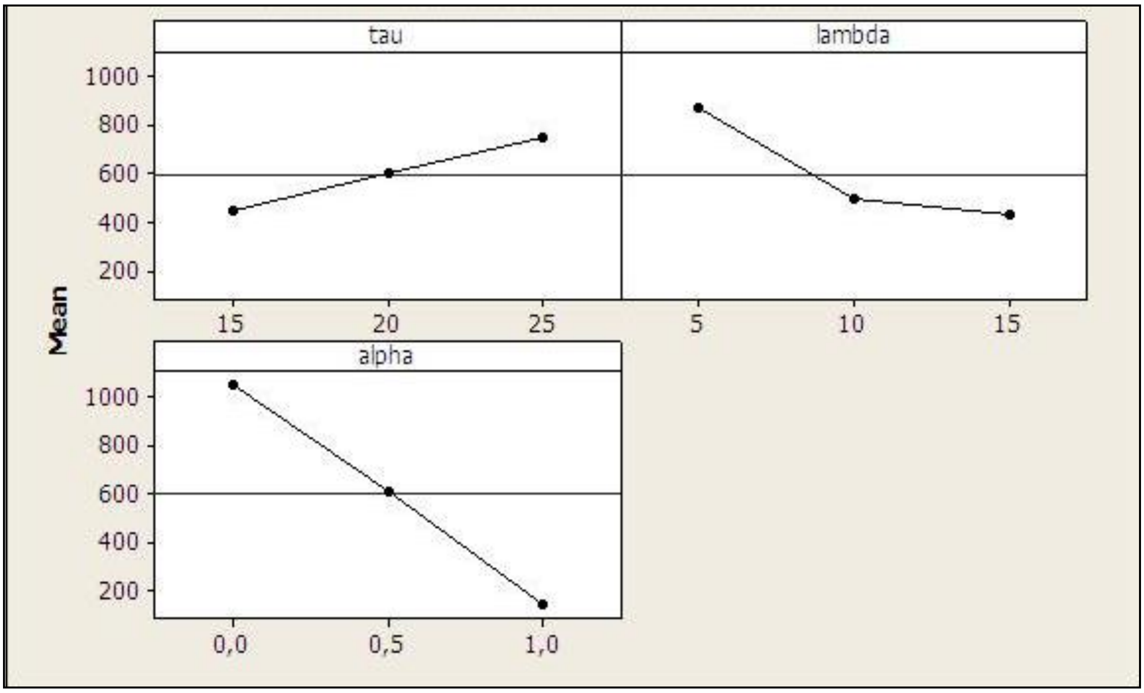

Figure 5.1 : Main effects plot for time for system stabilization

The interaction effect between these three parameters is shown in Fig. 5.2. Fig. 5.2 indicates that service delay time and proportion of information distortion act very much similar on time for system stabilization against capacity adjustment time. When service delay time and proportion of information distortion increase and capacity adjustment decrease, time for system stabilization increase. Furthermore, when the proportion of information sharing is high, there is not much difference on time for system stabilization based on the selection of capacity adjustment time and there is no difference on time for system stabilization based on the selection of service delay time. Because as it is mentioned before, "α = 1" means that only application start rate is used for setting the target capacity, not backlog or service delay time information. However, time for system stabilization increases very quickly as service delay time and proportion of information sharing decrease.

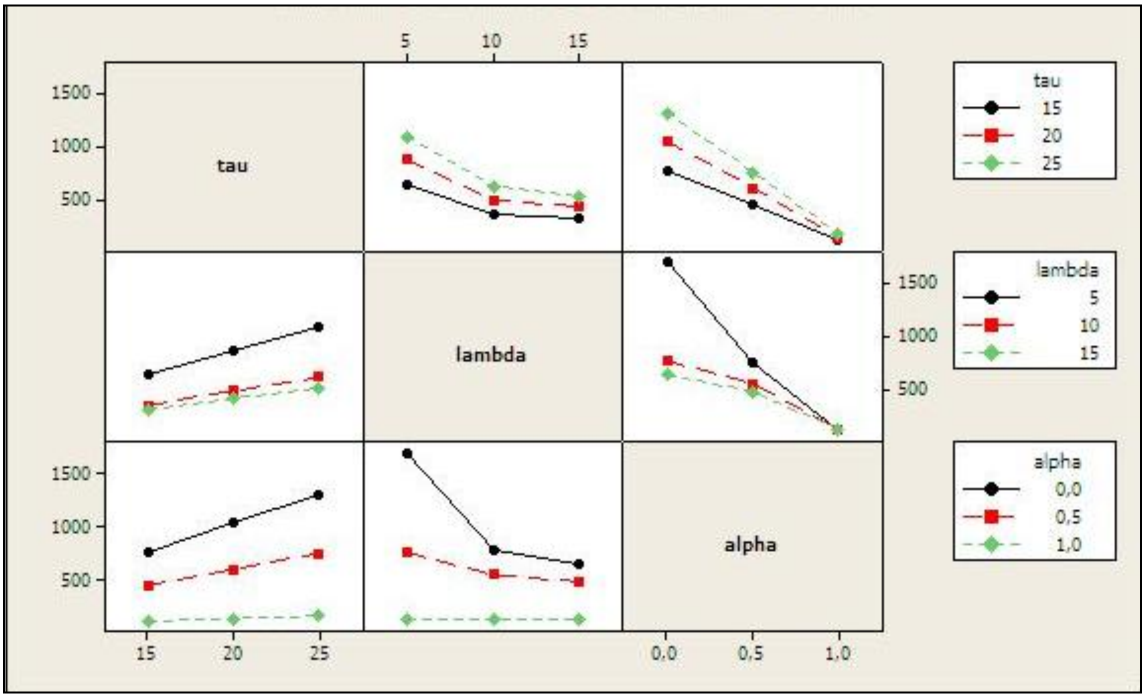

Figure 5.2 : Interaction plot for time for system stabilization

5.2 IMPACT OF FOUR PARAMETERS ON INFORMATION DISTORTION

The second aim of this study is to analyze the impact of capacity adjustment time, service delay time, proportion of information sharing and variability on application start rate on information distortion for a four-stage service supply chain. The graphics in Figures 4.3 and 4.4 are generated by simulating Equation (1) through (6) calculating bullwhip ratio over 2700-day period. In Figure 4.3, a graphical representation of the variation of bullwhip ratio with respect to capacity adjustment time, service delay time, proportion of information sharing and variability on application start rate is indicated for all stages of a four-stage service supply chain. In Figure 4.4, a graphical representation of the variation of bullwhip ratio with respect to the interaction of capacity adjustment time, service delay time and proportion of information sharing is shown.

5.2.1 Impact of Capacity Adjustment Time on Information Distortion

The graphics in Figure 5.1 indicate that bullwhip ratio is significantly influenced by capacity adjustment time at all stages. These graphics show that any increase in the value of capacity adjustment time (tau) parameter leads to an increase in the bullwhip ratio at all stages, except first stage. In contrast, the τ parameter on the bullwhip ratio displays different pattern at first stage. In other words, capacity adjustment time increases in inverse proportion to the increase of bullwhip ratio at first stage.

The interaction effect between capacity adjustment time and other three parameters is shown in the graphics in the first columns called as tau in Fig. 5.2. It is apparent form these graphics that service delay time and proportion of information sharing act very much similar on the bullwhip ratio against capacity adjustment time at all stages, except first stage. However, the impact of interaction between capacity adjustment time and variability on bullwhip ratio displays a slightly different pattern at last three stages. Fig. 5.2 shows that selection of relatively higher value for service delay time and medium level for proportion of information sharing enables to reduce the bullwhip ratio under all levels of capacity adjustment time at first stage. When we consider the interaction of the variability parameter with capacity adjustment time, Fig. 5.2 indicates that shorter capacity adjustment times always lead to increase the bullwhip ratio independently from the value of the variability parameter. Therefore, we can state that the variability parameter cannot contribute sufficiently to reduce the negative impact of shorter capacity adjustment times. For last three stages, Fig. 5.2 shows that interactions of service delay time and proportion of information sharing with capacity adjustment time have some similarities; selection of relatively higher values for service delay time and proportion of information sharing enables to reduce the bullwhip ratio under all levels of capacity adjustment time at last three stages. Likewise, selection of higher variability on application start rate can contribute to reduce the negative impact of all levels of capacity adjustment time.

5.2.2 Impact of Service Delay Time on Information Distortion

The graphics in Figure 5.1 indicate that bullwhip ratio is significantly influenced by service delay time at all stages. These graphics show that any decrease in the value of service delay time (lambda) parameter leads to an increase in the bullwhip ratio at all stages. These graphics reveal that the bullwhip ratio becomes the largest when the λ parameter is 5 and the smallest when it is 15. However, there is not much difference between the values of bullwhip ratio when the λ parameter increases up to 15 from 10.

The graphics in the second columns in Fig. 5.2 show the interaction effect between service delay time and other three parameters. It may be readily apparent from these graphics that interaction of each parameter with service delay time has some similarities at all stages, except first stage. These graphics in Fig. 5.2 shows that selection of medium level for proportion of information sharing and high level of capacity adjustment time enables to reduce the bullwhip ratio at all levels of service delay time at first stage. When we consider the interaction of the variability parameter with service delay time, Fig. 5.2 indicates that shorter service delay times always lead to increase the bullwhip ratio independently from the value of the variability parameter. Therefore, we can state that the variability parameter cannot contribute sufficiently to reduce the negative impact of longer service delay times at first stage. For last three stages, Fig. 5.2 indicates that the values of bullwhip ratio are almost same at high and medium levels of service delay time independently based on the selection of other three parameters. However, when the level of service delay time is low, there are increases in the bullwhip ratio. Since the bullwhip ratio is higher under low levels of service delay time as compared with the ones under high and medium levels of service delay time, the selection of relatively lower values of capacity adjustment time, higher values of proportion of information sharing and variability on application start rate becomes remarkably important to be able to reduce the bullwhip ratio under low service delay time.

5.2.3 Impact of Proportion of Information Sharing on Information Distortion

The graphics in Figure 5.1 indicate that bullwhip ratio is significantly influenced by proportion of information sharing at all stages. These graphics show that any decrease in the value of proportion of information sharing (alpha) parameter leads to an increase in the bullwhip ratio at all stages, except first stage. The graphics for last three stages reveal that the bullwhip ratio becomes the largest when the α parameter is 0 and the smallest when it is 1. However, there is not much difference between the value of bullwhip ratio when the α parameter increases up to 1 from 0.5. Surprisingly, this parameter on the bullwhip ratio displays different pattern at first stage. The graphic for first stage reveals that the bullwhip ratio becomes the smallest when the α parameter is 0.5 and the largest when it is 1. This result confirms the existence of a V-type relationship between the α parameter and the bullwhip ratio at first stage. It is most likely that there are significantly decreases in the bullwhip ratio as the value of the α parameter increases up to a point (0.5), and then it starts to increase with higher values of parameter.

The graphics in third columns in Fig. 5.2 show the interaction effect between proportion of information sharing and other three parameters. It may be readily apparent from these graphics that interaction of each parameter with the α parameter has similar behaviors on the bullwhip ratio at all stages, except first stage. When we consider the interaction of the variability parameter with proportion of information sharing, Fig. 5.2 indicates that the medium level of α parameter always leads to decrease the bullwhip ratio independently from the value of the variability parameter at first stage. Furthermore, the bullwhip ratio decreases as capacity adjustment time and service delay time increase under medium level of proportion of information sharing at first stage. For last three stages, Fig. 5.2 indicates that the values of bullwhip ratio are almost same at high and medium levels of proportion of information distortion independently based on the selection of other three parameters. However, when the level of α parameter is low, there are increases in the bullwhip ratio. Since the bullwhip ratio is higher under low levels of α parameter as compared with the ones under high and medium levels of α parameter, the selection of relatively lower values of capacity adjustment time, higher values of service delay time and variability on application start rate becomes remarkably important to be able to reduce the bullwhip ratio under low level of α parameter.

5.2.4 Impact of Variability on Application Start Rate on Information Distortion

The graphics in Figure 5.1 indicate that bullwhip ratio is significantly influenced by variability on application start rate at all stages, except first stage. There is not much difference on the bullwhip ratio based on the selection of the variability parameter at first stage. These graphics show that any decrease in the value of variability parameter leads to an increase in the bullwhip ratio at last three stages.

The graphics in the last columns in Fig. 5.2 show the interaction effect between variability on application start rate and other three parameters. For first stage, there is not much difference between the values of bullwhip ratio at each level of variability based on the selection of three parameters. For last three stages, Fig. 5.2 indicates that the values of bullwhip ratio are almost same at each level of variability independently from the high and medium levels of service delay time and proportion of information sharing. However, the selection of low levels of service delay time and proportion of information sharing enables to increase the bullwhip ratio at all levels of variability. In these situations, the values of bullwhip ratio are higher under lower variability. When we consider the interaction of capacity adjustment time with variability, Fig. 5.2 indicates that lower variability leads to increases in the bullwhip ratio almost independently from the value of capacity adjustment time. However, the bullwhip ratio has slightly lower values at all levels of variability under shorter capacity adjustment time.

Briefly, except for stage 1, bullwhip ratio has positive association with capacity adjustment time, proportion of information sharing and variability on application start rate. The longer capacity adjustment times and the higher proportion of information sharing and variability lead to increments on the bullwhip ratio. On the other hand, bullwhip ratio has negative association with service delay time. The shorter service delay time leads to increments on the bullwhip ratio. In contrast to the expectations, the impacts of these four parameters at stage 1 on bullwhip ratio are somewhat surprising.

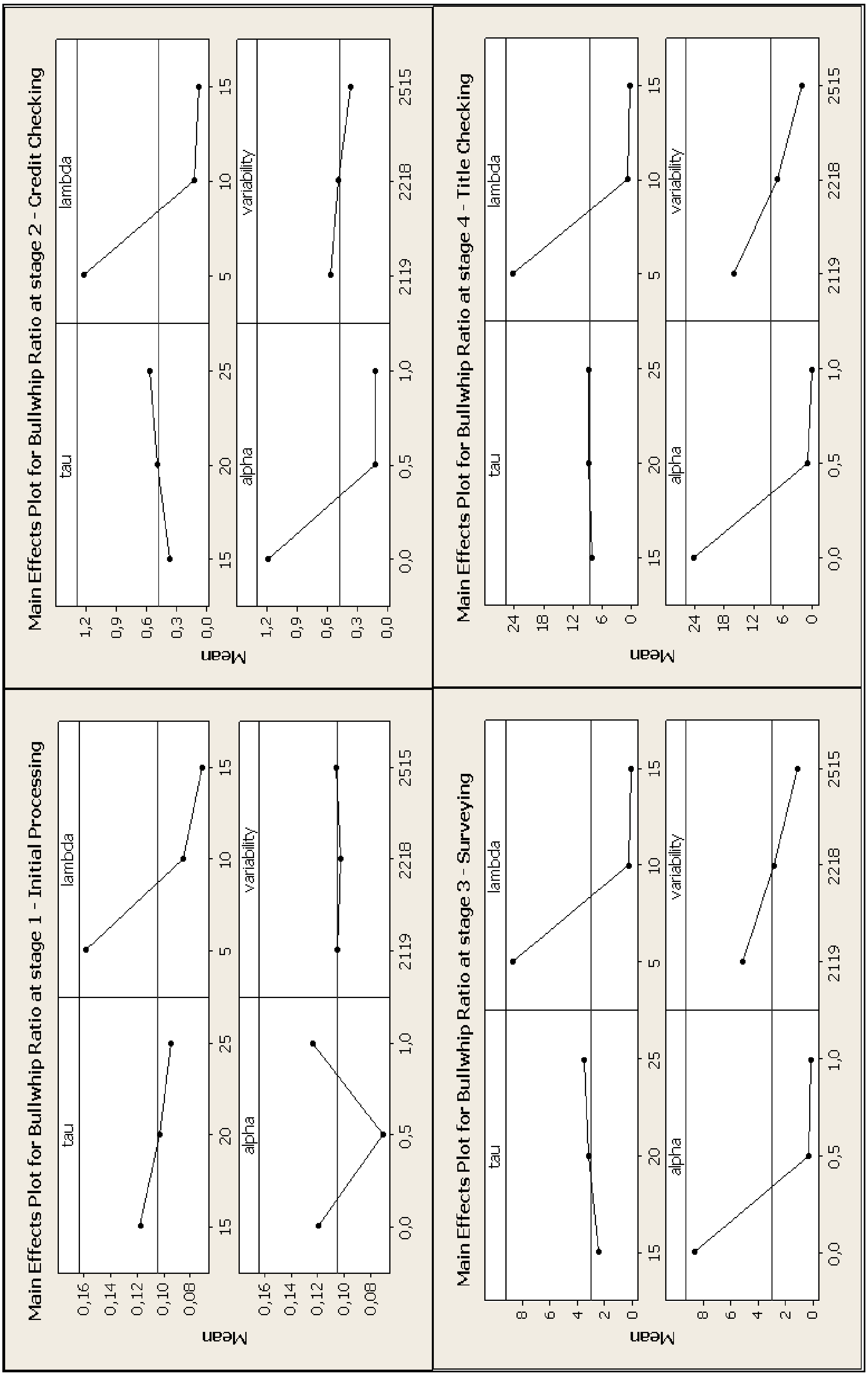

Figure 5.3 : Main effects plots for bullwhip ratio

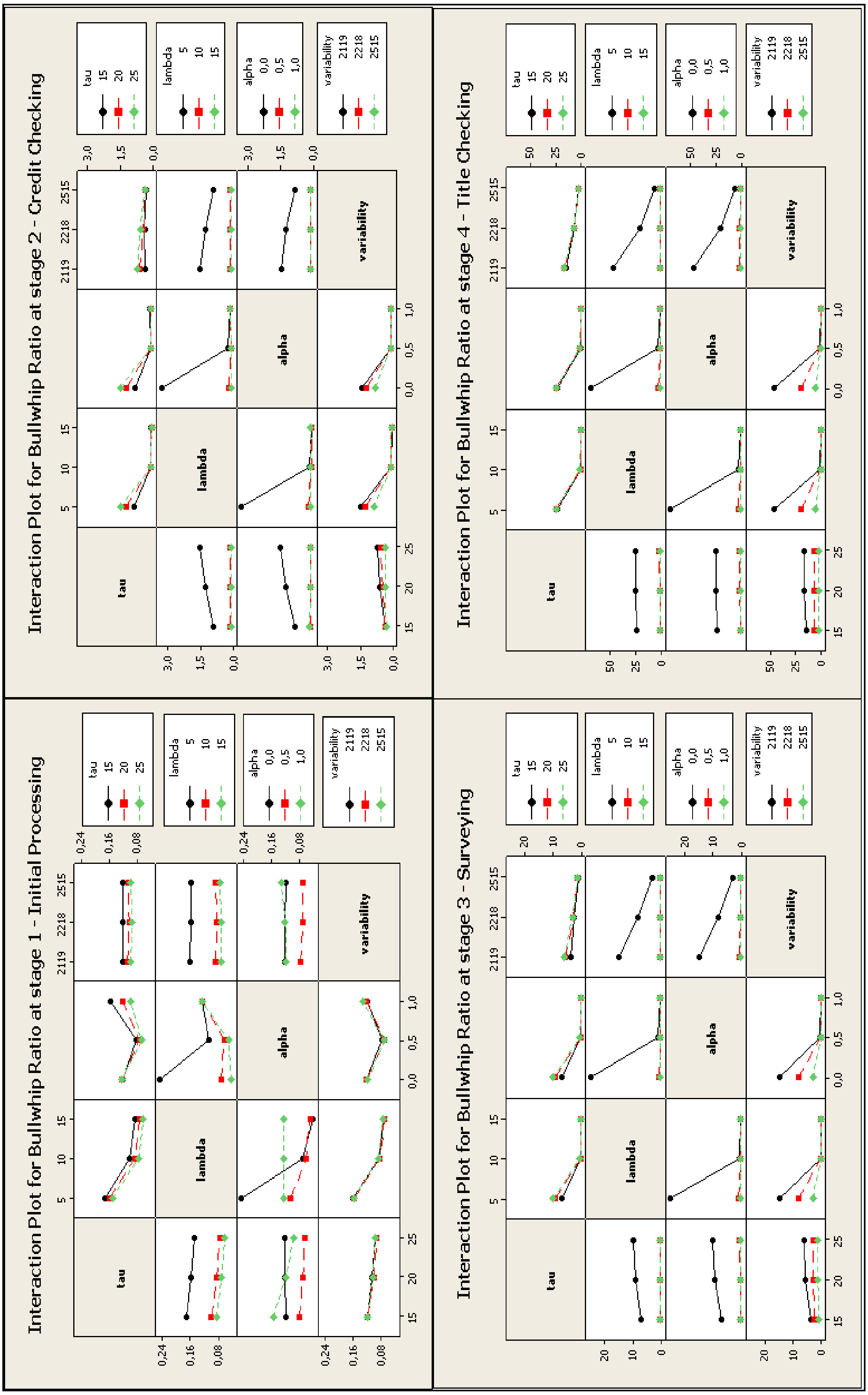

Figure5.4 : Interaction plots for bullwhip ratio

6. DISCUSSION & CONCLUSION

Over last decade, supply chain management has dramatically become the subject of almost all manufacturing companies as well as service companies that want to get a bigger share from increasingly competitive global marketing. The importance of supply chain management is not only interesting just today, it has been getting more value-added each day and in the future, it will be the key of the success to open almost every door for the manufacturing companies as well as service companies. In order to manage service businesses successfully and achieve sustainable competitive advantages in gradually more information technology intensive global marketing, the nature of services that are the differences between services and manufacturing industries are more important to be understood. With the development of service industry, some of the research papers have showed us that the supply chain theory can be considered and applied in service industry and in the future, its importance for companies will be more considered. The translation of supply chain management for service sectors is essential. As a matter of fact, based on the literature reviews the most appropriate supply chain framework is chosen to translate for a new service supply chain framework. The model includes all types of essential managements that are needed; capacity and skills management, demand management, customer relationship management, supplier relationship management, service delivery management and cash flow management. Moreover, information sharing and technology management are vital in order to hold every members of service supply chain effectively throughout the organization.

Where there is information sharing, there is a big problem which is how the individual systems thinking ability of service supply chain participants impacts the dynamics of the total service supply chain. This is called as information distortion as known as the bullwhip effect (BWE). Information distortion usually appears in the situation when each member of service supply chain takes steps individually and does not think about the others. The bullwhip effect has dramatically made service supply chain get worse and worse each day. Thus, when the companies face to the BWE, they should take immediate steps in order to protect themselves and their members’ priorities. They should analyze their situations and their relationship with their service supply chain's members. Then if there are any problems which are related with the BWE, they should immediately decide how they can handle it out and make their relationship get better with almost perfectly setup information systems which allow sharing information with non-exaggeration because the worst effect is caused by uncertainty between the members of supply chain.

The most famous and applicable game for bullwhip effect is the Beer Game in supply chain management. However, in services almost all orders are make-to-order. Because of that reason, Beer Game is not suitable for service supply chain. There is one game whose principles are almost the same as Beer Game's: Mortgage Service Game. This game is applied to simulate service supply chain in order to show information distortion and amplification on capacity planning. Besides the mortgage service game can be used to reveal supply chain management attitudes in a make-to-order situation. In section 4, it is introduced a simulation model for mortgage service game not only to demonstrate bullwhip effect on a four-stage service supply chain but also to provide how important information sharing is also. Mortgage Service Model is simulated with selecting common random numbers for application start rate so that all stages would face exactly the same application start rate conditions. As it was mentioned several times in literature, information sharing is as a remedy for bullwhip ratio. Based on the simulation analysis, this study noted a highly significant finding that low levels of capacity adjustment time and high levels of service delay time, proportion of information sharing and variability on application start rate have a positive impact on reducing the bullwhip ratio for all stages except initial stage. As an initial stage cannot respond to the variability of these four parameters immediately, it has different impacts on bullwhip ratio. Also, medium levels of proportion of information sharing and variability and high levels of capacity adjustment time and service delay time have slightly positive impact on reducing the bullwhip ratio. This study noted also a highly significant finding that low levels of capacity adjustment time and high levels of proportion of information sharing have a strongly positive impact on reducing times for system stabilization. Besides, high levels of service delay time have also a positive impact on reducing the days of system stabilization.

This study may further be extended to evaluate the impact of bullwhip effect on the performance measures of a four-stage service supply chain (e.g., backlog cost of the stages, total chain backlog cost, total cost of the stages, total chain cost) and to make information sharing through all stages and to use capacity information in order to calculate target capacity. Our calculations on target capacity are limited only to use backlogs and/or information of the application start rate. Also 20 replications may not be enough. The higher replication numbers would be applied. Examination of different equations on calculations of target capacity in a four-stage service supply chain would also be applied for future research (e.g., using capacity information of predecessor stages and/or successor stages).

The most significant managerial implication of this study lies in the need to share information across all chains to mitigate the bullwhip effect. While low capacity adjustment time and high service delay time would increase target capacity accuracy, they have also positive influences on the reduction of the bullwhip effect. SSC managers are therefore strongly suggested to operate information sharing by selecting higher value for α to keep the bullwhip ratio low, while at the same time to increase target capacity accuracy. Also SSC managers are suggested to select higher values for λ and variability, lower value for τ to reduce the bullwhip effect based on the results of this study.

Understanding and managing service supply chains are critical to any company's drive to improve productivity and profitability. In the shortest time, the companies should be aware of how important to manage service supply chain not for the companies' today but also for their futures. Finally, the truth is about not only to achieve almost all aims for the companies in service supply chain but also to take bigger advantages of this gradually developing global service markets, lying in the details of successfully management of service supply chain and consequently sharing global information across all chains for holding every chain (member) together more powerful as possible.

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APPENDIX

APPENDIX 1- Table A.1 – Formulas for Stage 1 in Microsoft EXCEL

Start		MORTGAGE SERVICE GAME (10 years)			
		Initial Processing	Credit Checking	Surveying	Title Checking
Capacity Adjustment Time	τ=	25	25	25	25
Delay Time	λ=	5	5	5	5
Proportion of Information Sharing	α =	0	0	0	0
Application Start Rate at the beginning	20				
0	Application Start Rate	Initial Processing			
DAY	completion rate (r)	completion rate (r)	capacity (C)	backlog (B)	target capacity (C*)
1	19	=MIN(E11;(F11+C11))	20	200	20
2	20	=MIN(E12;(F12+C12))	=((E11+((1/$D$5)*(G11-E11))))	=F11+C11-D11	=IF(MOD(B12;5)=0;(($D$7*C12)+(1-$D$7)*(F12/$D$6));G11)
3	19	=MIN(E13;(F13+C13))	=((E12+((1/$D$5)*(G12-E12))))	=F12+C12-D12	=IF(MOD(B13;5)=0;(($D$7*C13)+(1-$D$7)*(F13/$D$6));G12)
4	19	=MIN(E14;(F14+C14))	=((E13+((1/$D$5)*(G13-E13))))	=F13+C13-D13	=IF(MOD(B14;5)=0;(($D$7*C14)+(1-$D$7)*(F14/$D$6));G13)
5	21	=MIN(E15;(F15+C15))	=((E14+((1/$D$5)*(G14-E14))))	=F14+C14-D14	=IF(MOD(B15;5)=0;(($D$7*C15)+(1-$D$7)*(F15/$D$6));G14)
6	19	=MIN(E16;(F16+C16))	=((E15+((1/$D$5)*(G15-E15))))	=F15+C15-D15	=IF(MOD(B16;5)=0;(($D$7*C16)+(1-$D$7)*(F16/$D$6));G15)
7	21	=MIN(E17;(F17+C17))	=((E16+((1/$D$5)*(G16-E16))))	=F16+C16-D16	=IF(MOD(B17;5)=0;(($D$7*C17)+(1-$D$7)*(F17/$D$6));G16)
8	21	=MIN(E18;(F18+C18))	=((E17+((1/$D$5)*(G17-E17))))	=F17+C17-D17	=IF(MOD(B18;5)=0;(($D$7*C18)+(1-$D$7)*(F18/$D$6));G17)
9	19	=MIN(E19;(F19+C19))	=((E18+((1/$D$5)*(G18-E18))))	=F18+C18-D18	=IF(MOD(B19;5)=0;(($D$7*C19)+(1-$D$7)*(F19/$D$6));G18)
10	19	=MIN(E20;(F20+C20))	=((E19+((1/$D$5)*(G19-E19))))	=F19+C19-D19	=IF(MOD(B20;5)=0;(($D$7*C20)+(1-$D$7)*(F20/$D$6));G19)
11	19	=MIN(E21;(F21+C21))	=((E20+((1/$D$5)*(G20-E20))))	=F20+C20-D20	=IF(MOD(B21;5)=0;(($D$7*C21)+(1-$D$7)*(F21/$D$6));G20)
12	20	=MIN(E22;(F22+C22))	=((E21+((1/$D$5)*(G21-E21))))	=F21+C21-D21	=IF(MOD(B22;5)=0;(($D$7*C22)+(1-$D$7)*(F22/$D$6));G21)

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