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## ABSTRACT

## SERVICE SUPPLY CHAIN MANAGEMENT: A HIERARCHICAL DECISION MODELING APPROACH

by
**Roger Angel Solano-Cayama**

A Service Supply Chain (SSC) may be described as a network of service provider facilities (in-house or outsourced), each of which is able to process one or more service tasks on an as needed basis. Two key characteristics of a SSC are (i) the business service is decomposable into several sequential tasks that can be processed by different service providers, and (ii) the primary capacity resource is skilled labor. SSCs are increasingly being developed by companies that experience a high variability of demand for their services (e.g., loan processing, analytical consulting services, emergency repair crews, claims processing, etc.). Typically, the customer wait time penalty is very high, to the extent that if the service is not provided within a certain time, the customer service request will abort. As a result, the service provider needs to maintain sufficient processing capacity to meet peak levels of demand. The primary advantage of a SSC, relative to a traditional dedicated facility, is that the processing capacity (labor) can be economically adjusted (lower hiring and firing costs) to match changes in the current demand level.

In this dissertation, a hierarchical framework for modeling the decision structure in SSCs is developed. This framework introduces and defines the key SSC entities: service products, service jobs, service providers, and the parameters for characterizing the demand behavior. As part of the framework two problems are formulated and solved. First, given that Service Supply Chains are intended to be dynamic delivery networks that efficiently respond to demand variations, a *strategic problem* is which candidate service providers are selected to form the SSC network, and how the service tasks are assigned within the provider network. The problem is formulated and solved as a binary program. Second, a consequent *tactical problem* is how the workforce level at each service provider is dynamically adjusted (hiring and firing) as the real time demand data comes

in. The problem is formulated and solved as a linear program that bounds a mixed integer program (MIP).

The strategic model takes the demand parameters, the competing providers' information, and the service and tasks parameters, to select the providers that are going to become part of the SSC and assign tasks to them. A method to quantify cumulative demand variation per seasonal cycle is presented to derive aggregate demand parameters from the forecast. The design objective of the strategic model is to minimize set up cost and projected operational cost. The objective is achieved by simultaneously minimizing capital cost, hiring cost, firing cost, service delay cost, excess capacity cost, labor cost, and quality cost while fulfilling the capacity, tasks assignment, facility installation, and task capability constraints.

The tactical model is constrained by the providers and task assignment resulting from the strategic model. It uses a more accurate demand forecast, and minimizes actual operational costs represented by hiring cost, firing cost, backlog cost and labor cost, while fulfilling the production balance, routing, capacity, workforce balance and demand constraints. It is solved in two phases. A relaxed model is solved as an LP and its solution is used for bounding a MIP problem.

Finally, the behavior of the two models is studied by performing numerical experiments changing key supply chain parameters such as hiring and firing cost, demand variability, labor cost, and backlog cost.

SERVICE SUPPLY CHAIN MANAGEMENT:
A HIERARCHICAL DECISION MODELING APPROACH

by
Roger Angel Solano-Cayama

A Dissertation
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Industrial Engineering

Department of Industrial and Manufacturing Engineering

August 2008

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## APPROVAL PAGE

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To my son Robert Solano.

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# CHAPTER 1

# INTRODUCTION

A Service Supply Chain (SSC) may be described as a network of service provider facilities (in-house or outsourced), each of which is able to process one or more service tasks on an as needed basis. Two key characteristics of a SSC are (i) the business service is decomposable into several sequential tasks that can be processed by different service providers, and (ii) the primary capacity resource is skilled labor. SSCs are increasingly being developed by companies that experience a high variability in the demand for their services (e.g., loan processing, analytical consulting services, emergency repair crews, claims processing, etc.). Typically, the customer wait time penalty is also very high, to the extent that if the service is not provided within a certain time, the customer service request will abort. As a result, the service provider needs to maintain sufficient processing capacity to meet peak levels of demand. The primary advantage of a SSC, relative to a traditional dedicated facility, is that the processing capacity (labor) can be economically adjusted (lower hiring and firing costs) to match changes in the current demand level.

In this dissertation a hierarchical framework for modeling the decision structure in SSCs is developed. Certain service delivery systems have evolved over time into a network of service providers that fit the definition of a Supply Chain. However, the concepts and analytical models of "Supply Chain Management" were developed primarily for the manufacturing sector and focus on physical inventory. This dissertation addresses the need to apply the Supply Chain Management knowledge base to information based service systems.

According to the U.S. Bureau of Economic Analysis in the year 2004, the service Sector produced 70% of the gross domestic product generated by the private industry. By 1994, 71.5% of U.S. workers performed service jobs as managers, professionals, sales people, or technical support staff (van Biema et al., 1997). In the percentage of the workforce employed in services increased from 66.4% to 78.4% between 1981 and 2004 while manufacturing fell from 30.1% to 20% (Machuca et al., 2007). Clearly, research that would improve the performance of service delivery systems is relevant under the current conditions and trends.

A variety of service businesses experience high demand variability (e.g., loan processing, advanced consulting services, emergency repair crews, claims processing, etc.) and need to respond quickly to those demand changes. Limited capital resources and cost constraints limit the ability of the service delivery system to maintain a large fixed capacity to cover peaks in demand. Since, when demand is low, the capacity is underutilized and the fixed costs high. The combination of variable demand and limited financial resources are the key motivations to establish a SSC with flexible capacity.

When capacity is constrained, the arriving customer (or service request) joins a queue and waits to be served. In many cases, the customer wait time penalty is very high, to the extent that if the service is not provided within a certain time, the customer service request will abort. Typically, the service requests can be divided into several tasks, not necessarily sequential, performed by different entities. Between these different entities, there are material, information, and financial flows. Because of the intangible and perishable characteristics of services, there will be no inventory between the different tasks to decouple the stages in the service process. Instead, customer-waiting serves as the buffer between the different tasks. Figure 1.1 is a schematic representation of a service product delivered by a SSC. In general, the process of networking the service tasks is referred to as Business Process Outsourcing (BPO). In the specific case of a SSC, the network has the ability to adjust capacity dynamically according to changes in demand.

One of the main goals of SSCs is to decrease the labor resource costs by the increased labor flexibility (lower hiring and firing costs) of the service provider network. Some ways to achieve this goal is to have a flexible workforce, flexible facilities, and/or outsourcing. An organization might opt to build fixed resources and a permanent service delivery process. An arrangement like that provides several benefits including quality control and process control, but the premise is that in many situations this arrangement is not viable either economically or operationally. In such situations, the preferable option would be to set up a SSC. The primary company (SSC Leader) sets the SSC with in-house or outsourced facilities, often located in multiple geographies to exploit local cost advantages and expertise.

The key characteristic of a SSC are (i) the service products are decomposable into several sequential tasks that can be processed by different service providers, and (ii) the primary capacity resource is skilled labor. The key objective for a company to setup a SSC is to decrease the labor resource costs by increasing the labor flexibility (lower hiring and firing costs) of the networked providers, when the following conditions are present:

- The demand for a specific customer service product is highly variable with large shifts, and as a result, rapid changes in processing capacity are needed to maintain a target service delivery time.

- The service tasks require a wide range of expertise. Often an individual expertise is best accessed from a service provider that is solely focused on it.

- Capital constraints limit the ability to built and develop the process capability required to perform the service task.

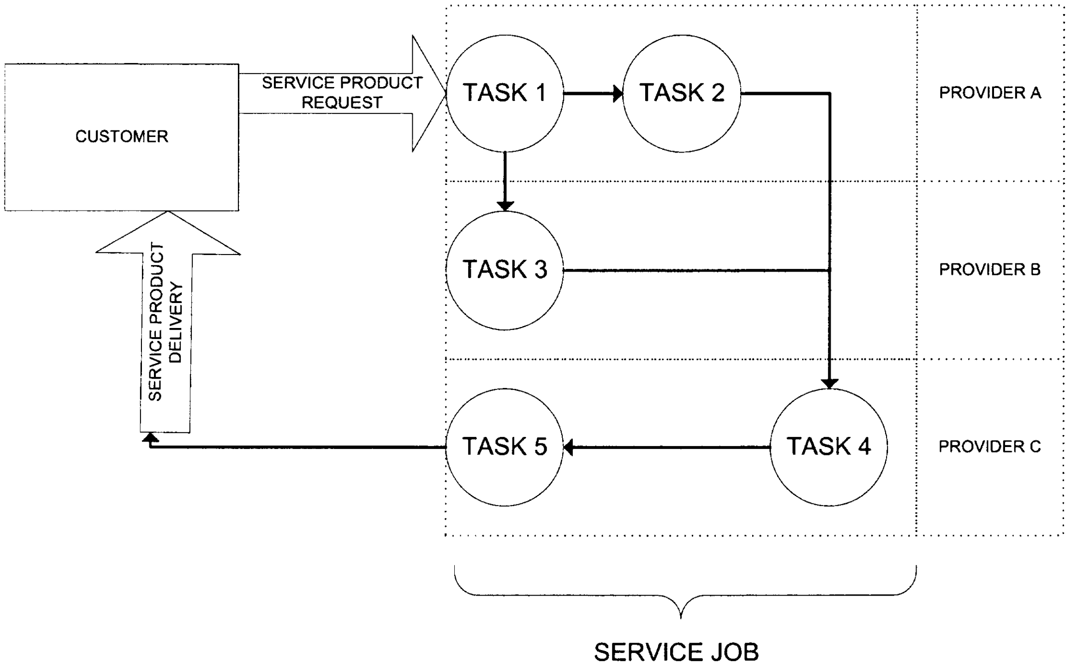



**Figure 1.1** Service product delivered by a Service Supply Chain.

Given the current trend towards integration in the world economy, the advances in information systems, telecommunication networks and workflow platforms, Service Supply Chains will continue to grow worldwide. Continuous research is required to apply scientific decision making to the design and operation of a Service Supply Chain.

## 1.1 Problem Description

A SSC is a service delivery systems established as a network of service providers, each with a specific expertise. Building and operating the Service Supply Chain requires making different decisions. Some of these decisions are shown in Figure 1.2. The objective is to deliver a high quality service in a timely fashion while minimizing capital expenses and operating cost. Setup, operating (labor) costs, process efficiency, productivity, and the flexibility to adjust staffing levels vary among the different options available. Once the providers are selected and the tasks are assigned to them, the Service Supply Chain is constrained by the capabilities of its members in their ability to respond to demand variations.

To improve the performance of SSCs a 2-Level hierarchical model is needed for their design and operation. Level-1 is a strategic model and decides which providers, from a list of candidates, are selected to become part of the SSC, as well as what service tasks are assigned to each. Level-2 is a tactical model and decides the capacity adjustments at each provider on a cyclical basis. Mathematical models for those two levels are developed in this dissertation.

At the strategic level, the objective is to minimize the setup cost and the projections of the operational cost. At the tactical level, the objective is to minimize the sum of the service delays and operational costs. The objective of both models is to reduce costs across the chain. The two levels consider the dynamics of a service delivery system that integrates different service providers across different service products. A binary programming model is developed for the strategic level and a mixed integer-programming model is developed for the tactical level. The problems addressed by each model are:

- Strategic Problem: Select the service providers (facilities) that will become part of the Service Supply Chain, and assign specific tasks to those facilities.
- Tactical Problem: Manage the workforce level in order to satisfy demand and reduce cost.

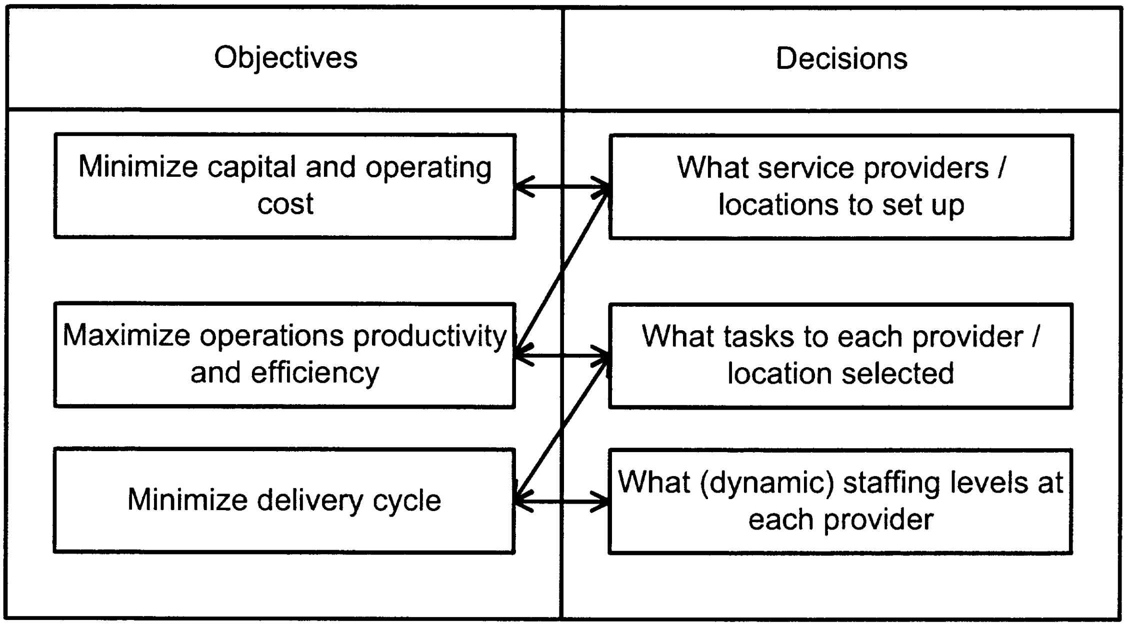



**Figure 1.2** Basic Service Supply Chain decisions.

The level-2 model is used on a fixed short-term cycle basis (e.g., monthly or quarterly) while the level-1 model is solved once per design cycle (every few years). At the strategic level, the objective is to minimize total system costs including labor, hiring and firing, service delay, service quality, and capital. While at the tactical level, the cost function includes the immediate capacity costs and the related service delay costs. A key issue in developing the strategic model is characterizing demand variability and how it affects capacity decisions. A method to determine aggregated demand parameters that describe the expected demand changes is presented.

The mortgage processing industry illustrates an example of a Service Supply Chain. Given the current characteristics of the financial industry, mortgage-processing products are delivered through a network of providers that fits the definition of SSC.

An example of the activities involved in the mortgage origination process is given in Figure 1.3. Other examples of services that can be sourced through a Service Supply Chain are presented in Table 1.1. These services are labor intensive with differentiated multiple tasks where each task requires different skills and equipment.

**Table 1.1** Examples of Services That Can Be Sourced Through a Service Supply Chain

| **Service** | **Industry** |
|---|---|
| **Mortgage application processing** | **Banking, Financial Industry** |
| **Architecture and building design** | **Construction** |
| **Corporate auditing and accounting** | **Accounting** |
| **Medical Analysis and diagnostic services** | **Healthcare** |
| **Electrical Grid repair and rebuild services** | **Utilities** |

Service supply chains are already being set up in the financial sector. Progeon (an Infosys subsidiary in Bangalore, India) entered into an agreement with GreenPoint Mortgage, the sixth largest U.S. wholesale mortgage lender, to provide business process management services ("Case Study: Inside the Progeon-Greenpoint Mortgage Transaction - Knowledge@Wharton," 2007). E-Loan, an online lender, outsourced the underwriting functions for their home equity business unit to Wipro Ltd.—an Indian outsourcing company. E-Loan offers their customer the choice of having their application processed in India or domestically. The domestic process is two days longer. In 2004, E-loan reported that 87% of its customers had chosen to have their application processed in

India at a cost saving to the company of about 60%. They are considering expanding this approach to other products (Drucker et al., 2004; Lancaster, 2004; Rai, 2004).

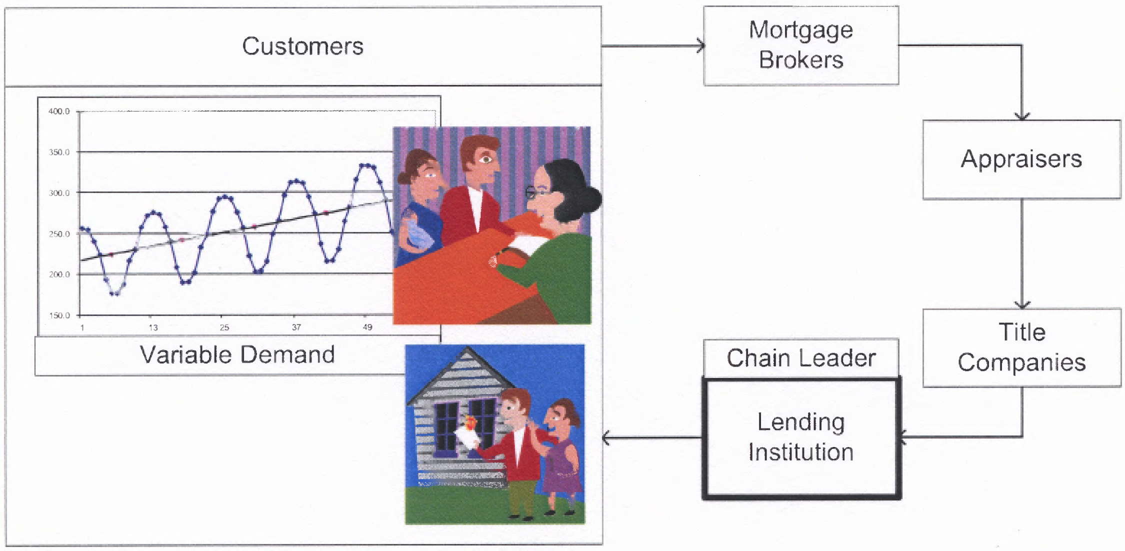



**Figure 1.3** Schematics of a mortgage origination process.

In Service Supply Chains the chain leader, (in this case the lending institution) selects the service provider and sets up the chain. Traditionally, the lending institution executed most the functions in-house, but now they distribute some functions among different service providers.

## 1.2 Research Statement

In this dissertation a hierarchical framework for modeling the decision structure in SSCs is developed. This framework introduces and defines the key SSC entities: service products, service jobs, service providers, and the parameters for characterizing the demand behavior. As part of the framework, two problems are formulated and solved.

First, given that Service Supply Chains are intended to be dynamic delivery networks that efficiently respond to demand variations, the *strategic problem* is to select the service providers to form the supply network, and to assign the service tasks within the provider network. The problem is formulated and solved as a binary program.

Second, the consequent *tactical problem* is to dynamically adjust the workforce level at each service provider (hiring and firing) as the real time demand data comes in. The problem is formulated and solved as a linear program that bounds a mixed integer program.

The concept and philosophy of "Supply Chain" and "Supply Chain Management" were born in the manufacturing environment and physical inventory based industries. Because of the differences between the manufacturing and services sectors, there is a need to provide a new theoretical framework to apply Supply Chain Management concepts to information based services. There is also a need to provide practical applications and quantitative models to assist in different hierarchical levels of decision making related to these supply chains. The decisions made could greatly affect the costs, quality, and speed of a service delivery processes.

## 1.3 Research Objectives

The research effort presented in this dissertation has the following objectives:

- To develop a hierarchical framework for the modeling and analysis of Service Supply Chains. This will identify the key entities, system parameters, and an associated hierarchical decision process.
- To develop a strategic decision making model for characterizing the service demand process followed by the selection of service providers, from a list of candidates. The model also assigns service tasks to the selected facilities. The

objective is to minimize both the capital costs, operating costs (labor and quality), and the labor flexibility costs (Hiring, Firing).

- To develop a tactical decision making model that adjusts the workforce level in real time based on actual demand levels.
- Analyze the strategic and tactical models in several case studies to assess the validity and utility of the models.

## 1.4 Dissertation Organization

This dissertation is organized into seven chapters. Chapter 1 introduces the research problem and the research objectives to be achieved. Chapter 2 discusses the results of the literature review on service management, supply chain management for the service sector and various models and techniques employed in the past. Chapter 3 presents the hierarchical framework for service supply chains, including definitions, key entities, characterization of demand, and an example. Chapter 4 illustrates the strategic level and the provider selection and task assignment model. Chapter 5 presents the tactical level and the workforce level model. Chapter 6 and 7 present the numerical experiments and conclusions. The appendix illustrate in details the method proposed to determine demand parameters.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Defining Services

There are several definitions of services. Quinn defines services to "include all economic activities whose output is not physical product or construction, is generally consumed at the time it is produced, and provides added value in forms … that are essentially intangible concerns of its first purchaser" (Quinn et al., 1987). Murdick defines services as "economic activities that produce time, place, form, or psychological utilities" (Murdick et al., 1990).

Fitzsimmons and Fitzsimmons conducted a survey of several definitions and found the common theme of intangibility and simultaneous consumption (Fitzsimmons et al., 2004). They define services as a time-perishable, intangible experience performed for a customer acting in the role of co-producer. They state that as of 1999 "the service sector accounts for more than 80% of total employment in the United States." They identify the distinctive characteristics of service operations as:

- The customer is a participant in the service process.
- Simultaneous production and consumption of services.
- Time-perishable capacity.
- Labor intensiveness.
- Intangibility.
- Difficulty measuring output.

They define the service package "as a bundle of goods and services that is provided in some environment" and identify four features of this bundle: supporting facility, facilitating goods, explicit services, and implicit services. Upon analyzing customer perception of quality, they conclude that waiting-time length and variation can have a highly negative impact on service quality, making backlog management critical to service firms.

All services can be classified into one or more of four categories (Lovelock, 1983; Sampson, 2000):

- Services that act on people's minds (e.g., education, entertainment, psychology).
- Services that act on people's bodies (e.g., transportation, lodging, funeral services).
- Services that act on people's belongings (e.g., landscaping, dry cleaning, repair).
- Services that act on people's information (e.g., insurance, investment, legal services).

## 2.2 Performance Measures

The definitions of appropriate performance metrics and how to fairly share the risks and rewards within the Service Supply Chain are of high importance. Cost savings are not the only motivators for establishing a Service Supply Chain—the performance measures should be aligned with corporate strategy and business goals.

There are several examples of companies that outsourced some tasks of the Service Supply Chain to reduce cost, only to reverse their decision later due to low quality and the resulting loss of customers. This is especially critical when the outsourced tasks involved customer encounters. For example, Dell, Capital One, and JPMorgan

Chase reversed plans to deliver front-line customer-service using outside contractors after realizing that "the hidden costs far outweighed the potential savings in labor expenses." (Pfeffer, 2006). To avoid unwanted results, decisions on Service Supply Chain configuration and the evaluation of its day-to-day performance should be measured in customer perception of quality, operational performance, and financial efficiency.

Trying to understand the nature and determinants of service quality, causes of service quality problems and strategies for dealing with them, Parasuraman (Parasuraman et al., 1985, 1988, 1991) conducted several studies and concluded that:

- Customer perceptions of service quality result from comparing expectations prior to receiving the service and actual experiences with the service.
- Quality evaluations derive from the service process as well as the service outcome. The manner in which the service is performed can be a crucial component of the service from the consumer's point of view.
- Service quality is of two types. First, there is the quality level, at which the regular service is delivered. Second, there is the quality level at which "exceptions" or "problems" are handled. Delivering good service quality requires strength at both levels.
- When a problem occurs, the low contact service firm becomes a high contact firm. Interactions between customer and company representatives can figure prominently in the quality image of the firm.

From interviews with focus groups, they identified ten determinants of service quality and created a system for measuring quality called SERVQUAL:

- Reliability: consistency of performance and dependability.
- Responsiveness: willingness or readiness of employees to provide service.
- Competence: possession of the required skills and knowledge to perform service.
- Access: approachability and ease of contact.
- Courtesy: politeness, respect, consideration, and friendliness of contact personnel.

- Communication: keeping customers informed in a language they can understand. Listening to customers.
- Credibility: trustworthiness, believability, honesty.
- Security: freedom from danger, risk, or doubt.
- Understanding the customer: making the effort to understand the customer's needs.
- Tangibles: include the physical evidence of the service.

They later reduced the ten determinants to five dimensions:

- Reliability: ability to perform the promised service dependably and accurately.
- Assurance: knowledge and courtesy of employees and their ability to inspire trust and confidence.
- Tangibles: physical facilities, equipment, and appearance of personnel.
- Responsiveness: willingness to help customers and provide prompt service.
- Empathy: caring, individualized attention the firm provides its customers.

Defining and measuring service quality is an ongoing debate. Cronin proposes a system called SERVPERF that is performance based instead of perceptions-minus-expectations (Cronin Jr et al., 1992, 1994). They state that service quality should be measured as an attitude and support the performance based measure of service quality. Their results suggest that service quality is an antecedent of consumer satisfaction and that consumer satisfaction exerts a stronger influence on purchase intentions than service quality. They recommend that managers may need to emphasize total customer satisfaction programs over strategies centered solely on service quality.

The SERVQUAL and SERVPERF models are centered on the service encounter. In Service Supply Chains, the service encounter is part (an important part) of a more complex system. Grönroos proposed a model of service quality based on two dimensions technical quality and functional quality. The technical quality is "what the customer receives" the service per se, "How he gets the technical outcome" is the functional quality. The technical quality is a result of the expertise of the firm, good technical solutions, technical abilities of the employees, appropriate use of machines and computer based systems. However, the customer is not only interested in what he receives as an outcome of the productions process, but in the process itself (since in service the customer is an integral part of the delivery process). How he gets the technical outcome is also important. Grönroos calls this quality dimension functional quality, and it corresponds to the expressive performance of a service. He concludes that the functional quality seems to be a very important dimension of the perceived service. In some cases, it is more important than the technical quality dimension. The quality dimensions are interrelated. An acceptable technical quality can be thought of a prerequisite for a successful functional quality (Gronroos, 1984). This dissertation proposes that the marketing and service encounter centered approach alone is incomplete for Service Supply Chain management. A new framework for Service Supply Chain performance measures will be developed.

The buyer-seller interaction is necessary for the service delivery process. Customer-supplier duality is present in the Service Supply Chain (Sampson, 2000). Price proposes a framework for analyzing service encounters based on the dimensions of duration, affective content, and special proximity (Price et al., 1995). In Service Supply Chains, the customer is an integral part of the system. He delivers inputs, starts the service request, receives the delivered service, evaluates its quality, and serves as a marketing tool by spreading his experience with word of mouth. Customer encounters, understood as face-to-face interactions between customer and service provider, have traditionally been studied in service operations management research. Services with high information content are more likely to be mediated by technology. Froehle proposes a measurement scale for technology mediated customer service encounters. They applied the general structure of the B–A–I model (belief → attitude → intention) for developing the measurement scales. Figure 2.1 presents their conceptual archetypes of customer contact in relation to technology. Figure 2.2 presents their Conceptual B–A–I framework of technology-mediated customer service hypothesized domains and constructs (Froehle et al., 2004).

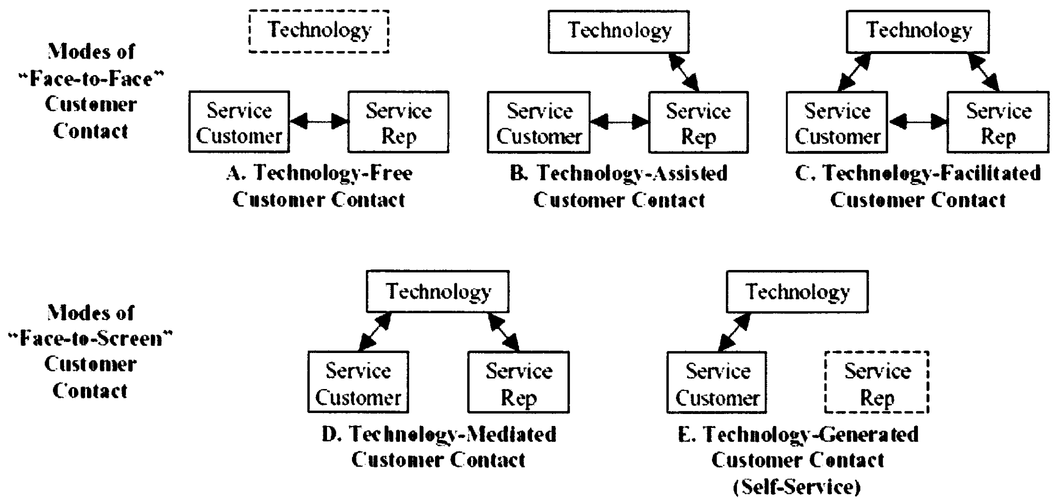



**Figure 2.1** Conceptual archetypes of customer contact in relation to technology.
Source: Froehle C.M. Aleda V.R. "New measurement scales for evaluating perceptions of the technology-mediated customer service experience" Journal of Operations Management 22 (2004) 1–21.

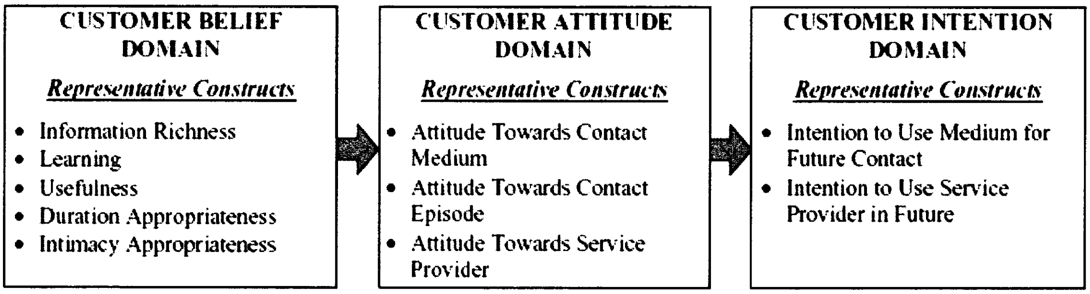



**Figure 2.2** Conceptual B–A–I framework of technology-mediated customer service.
Source: Froehle C.M. Aleda V.R. "New measurement scales for evaluating perceptions of the technology-mediated customer service experience" Journal of Operations Management 22 (2004) 1–21.

Grönroos (Gronroos et al., 2004) analyze service productivity and propose the following formula:

$$Service\ Productivity = \frac{revenues\ from\ a\ given\ service}{cost\ of\ producing\ this\ service} \quad (2.1)$$

$$Service\ Productivity = \frac{total\ revenue}{total\ cost} \quad (2.2)$$

Most of the literature focuses mainly on marketing with a strong emphasis on the functional quality and customer perceived quality. Service Supply Chain Management will be presented in this dissertation as a way to improve the technical quality dimension of the service delivery system, and reduce cost by adjusting capacity to changing demand and at the same time keeping the service delivery system responsive to those changes in demand. Three main criteria are proposed as Service Supply Chain performance measures: customer perception of quality, operational performance, and financial efficiency. These three criteria need to be adopted according to the firm's strategic goals, competition, technical advances and capabilities, financial resources and customer expectations.

## 2.3 Security Concerns in Service Supply Chains

Concerns about security in outsourcing and off shoring are currently a hot topic. Monitoring third party employees, adjusting to foreign legal systems and performing third party employees' background checks, especially if they are located offshore, are serious challenges to the Service Supply Chain security. When considering service providers to become part of the Service Supply Chain, it is necessary to evaluate their security practices, intellectual property protection, risk of security breaches, and privacy concerns. This risk is highlighted by a recent case were "a Pakistani subcontract worker threatened to post U.S. patients' medical data on the Web if claimed back pay was not forthcoming." (Weinstein, 2004) Third party service task providers are adjusting their security measures to address these concerns. They also obtain certifications by international standards bodies like ISO 17779 (information systems security standard). Security concerns should be properly considered and managed. They are the object of research for information security specialists and will not be addressed here.

## 2.4 Hierarchical Production Planning and Supply Chains

A classic and widely accepted framework for the decision making process was presented by Anthony in 1965. Miller (2001) reviews current hierarchical planning approaches and techniques and the exploration of how to broadly apply these to supply chain management.

He cites Anthony (1965) as classifying all managerial decisions into three broad categories: (1) strategic planning, (2) management control and (3) operational control. He states that a number of authors have termed the second category as operational control and the third as operational planning and scheduling. He uses the terms strategic planning, tactical planning, and operational planning. He cites Anthony (1965), offering the following definition of the role of strategic planning: "the process of deciding on objectives, on the resources used to obtain these objectives, and on the policies that are to govern the acquisition, use and disposition of these resources." He presents the following sample of typical strategic logistics issues and problems:

- Plant warehouse locations, missions and relationships (i.e., network infrastructure and design)
- New plant locations and sizes, and plant closings.
- Plant and warehouse capacity levels.
- Plant and warehouse technology and equipment acquisition.
- Plant and warehouse design.
- Owned assets vs. third party resources utilized (i.e, outsourcing decisions)
- Transportation network and transportation providers
- Order fulfillment approach (e.g., make –to-order vs. make-to-stock)

He states that a firm must evaluate these decisions in the context of a relatively long planning horizon. He mentions the higher risk and uncertainty associated with strategic planning decisions, and that they frequently involve major capital investments. "In the long run, these decisions will determine the competitiveness and profitability of a firm." He also mentions the need for broad aggregated informational inputs to make decisions.

When presenting the tactical planning level, and in the context of Anthony's framework, he says that the decision making process primarily focuses on resource allocation and resource utilization. He cites Anthony, stating that manager's tactical planning activities must obtain and use resources effectively and efficiently to assure the accomplishments of the firm's objectives. "The decision making process must focus on how to most effectively utilize the infrastructure and capacity that the implementations of strategic decision has created." As a sample of some of the more common tactical logistics decision, he mentions the following:

- Assignment of production capacity to product families, by plan (and often) by medium size time periods (e.g., quarters)
- Planned manufacturing capacity utilization rates, by plan and network wide.
- Workforce requirements (regular and overtime levels)
- Sourcing assignment (Plant-Distribution center-sales region/country).
- Inter-facility (e.g., inter-distribution center) shipment plans.
- Inventory investment and deployment plans.
- Transportation mode and carrier selections.

On operational planning and scheduling, he says that at this level, the firm must carry out the resource allocation and utilization decisions made at the tactical level in the daily and weekly activities, which occur at the operational level. At the tactical level, the firm makes the resource allocation decisions to facilitate the operations of the business, and at the operational level, the firm executes its daily operations using the resources made available by the tactical planning process.

He states that it would essentially be impossible to construct "one" model to provide decision support for all planning decisions ranging from strategic to operational. From a practical sense, it is very difficult to design one decision support model to address the complex hierarchy of decisions that must be made. Another motive for developing a hierarchical planning approach is the varying degrees of uncertainty and detail found in different decisions. Decisions made at each level also affect the other levels of the hierarchy. Decisions made at the strategic level place constraints on the tactical level and ultimately the operational level, while decisions made at the tactical level constrain the operational level. Decisions made at the operational and tactical levels provide feedback to evaluate decisions made at the tactical and strategic levels respectively.

He presents a brief review of the following selected key questions to consider in designing a hierarchical production planning system:

- How many planning levels should the hierarchical system have?
- What activities and processes should occur at each level of the planning hierarchy?
- What are the key problems which must be solved at each level?
- What planning models or decision support system should exist to solve the key problems at each level?
- What methodologies or algorithms should be used to solve each problem?
- How should data and other informational inputs and outputs be aggregated and disaggregated at each hierarchical level?
- What are the key linkages between the different planning levels? How do decisions made at higher levels flow down to lower levels and how do decisions made at lower levels provide feedback to higher levels?
- How can the system be designated to best match the organizational structure and hierarchy of the firm?
- How can the potential for sub-optimization introduced by a hierarchical approach be measured?
- What is the proper balance between designing simple and manageable systems, yet imbedding sufficient complexity and detail to realistically model the operation?
- How can the effectiveness of the overall system be measured?

He then presents several classical approaches used in hierarchical production and distribution planning. All the models presented are based on a physical inventory and therefore cannot be applied directly to information-based services. This dissertation follows the framework he presents to develop a hierarchical decision system for Service Supply Chain management.

Chopra et al. (2004) define decision phases in a supply chain. They state that decisions in supply chain management "fall into three categories or phases, depending on the frequency of each decision and the time frame over which a decision phase has an impact." These categories are Supply Chain Strategy or Design, Supply Chain Planning and Supply Chain Operation.

- Supply Chain Strategy: "During this phase, a company decides how to structure the supply chain over the next several years. It decides the chain configuration, how resources will be allocated, and what processes each stage will perform."
- Supply Chain Planning: "The supply chain configuration determined in the strategic phase is fixed. This configuration establishes constraints within which planning must be done. Companies start the planning phase with a forecast for the coming year of demand in different markets. Planning decisions include decisions regarding which markets will be supplied from which locations, the subcontracting of manufacturing, the inventory policies to be followed, and the timing and size of marketing promotions." "As a result of the planning phase, companies define a set of operating policies that govern short-term operations."
- Supply Chain Operations: "The time horizon is weekly or daily, and during this phase companies make decisions regarding individual customer orders. At the operational level, supply chain configuration is considered fixed and planning policies are already defined. The goal of supply chain operations is to handle incoming customer orders in the best possible manner. During this phase, firms allocate inventory or production to individual orders, set a date that an order is to be filled, generate pick list at a warehouse, allocate an order to a particular shipping mode and shipment, set delivery schedules of trucks, and place replenishment orders."

They also state that maximizing the overall value generated is the objective of a supply chain. They define value as the difference between what the final product is worth to the customer and the effort the supply chain expends in filling the customer's request. Value will be strongly correlated with supply chain profitability, which they define as the difference between the revenue generated from the customer and the overall cost across the supply chain. This definition of supply chain profitability is compatible with the definition of service productivity proposed by Grönroos (2004). Chopra presents several models for supply chain management again based on manufacturing and physical inventory and not applicable directly to information-based services.

## 2.5 Supply Chain Management in the Service Sector

Cook, DeBree and Feroleto (2002) wrote an article trying to apply supply chain management concepts originally developed for manufacturing to the service industry. They state that Supply chain management (SCM) is a familiar concept in manufacturing, but service industries are just now recognizing the value of successfully implementing it. They try to show "that implementing effective SCM is an advantage for companies that provide services." They describe five tools of SCM that can be applied to the service sector: making and keeping relationships, implementing new technology in the supply channel, the use of forecasting to increase supply chain effectiveness, outsourcing to increase efficiency, and cost management as a strategic weapon. They also present a case study from the health care industry. They analyze the application of the five tools for supply chains in the service industry. However, they talk about generalities and not about problems and solutions specific to the service sector. Even in the case study that they present, the emphasis is made on inventory reduction and JIT inventory management.

When talking about the benefits of SCM they do it again in a general sense, mentioning benefits as decreased lead times, faster product development, increased quality, and reduced costs. They mention that SCM greatly improves customer service and contributes to synergy within the process, and that this is especially crucial in service industries, where the emphasis is on meeting the customer's needs. They state that all of the benefits lead to greater competitiveness.

When they talk about the limitations of SCM, they do it again in a general sense, mentioning that there may be severe resistance within the company when implementing SCM, because it requires modification of the attitudes and behavior of those involved in the system - employees and the employer. Those limitations mentioned are again general problems and not problems specific to the service sector. The importance of this article is that the authors recognize and highlight the increasing importance of SCM in the service industry, but the article fails to address aspects specific to this particular problem.

Macdonald (1994) studies the successful implementation of total quality management (TQM) in service organizations. He states that this requires an understanding of the intrinsic differences between service and manufacturing organizations. Some differences are generic to the whole service field and others are specific to certain sectors of the service arena. He addresses the generic factors and differences summarized in Table 2.1

He concludes: "This article has shown that there is a real need for quality improvement in the service sector. It has also demonstrated that there are substantial differences between manufacturing and services. The carpenter and the joiner use the same tools but they use them in very different ways. The service organizations will therefore have to implement and use the tools of TQM in their own unique way." This article applies tools that were first developed in the manufacturing sector to the service industries and it recognizes the need to address the differences between the two sectors r to successfully implement these tools.

**Table 2.1** Differences between Products and Services

| PRODUCT | SERVICE |
|---|---|
| The customer receives a tangible product in the form of goods which can be seen and touched | The customer receives an intangible service which may or may not satisfy |
| The goods remain with the customer | Services are consumed at the moment of delivery |
| The production and delivery of goods are usually separated | Production, delivery and consumption of services are often at the same time |
| Few producers deal with customers | Most producers deal with customers |
| The customer is rarely involved with production | The customer is often closely involved with production |
| Goods can be serviced | Services have already been consumed and cannot be serviced |
| Goods are subject to liability but the producer has more opportunity to ameliorate the effect on the customer and thus the financial penalty | Services which do not meet the requirements are difficult replace--the financial impact is usually total |
| Goods can be purchased to store in inventory to satisfy the customer's needs | Services cannot be stored but must still be available on customer demand |
| Goods can be transported to the point of sale | Some services are transportable (e.g., information through communication lines) but most require the transportation of the service provider |
| The quality of goods is relatively easy for customers to evaluate | The quality of services is more dependent on subjective perception and expectation |
| Goods are often technically complex--the customer therefore feels more reliant on the producer | Services appear less complex--the customer therefore feels qualified to hassle the producer |

Source: Macdonald, J. (1994) Service is different. The TQM Magazine. Vol. 6 (1).

Gummesson (1994) tries to present new paradigms and service management issues for the future based on his own experience. He highlights a new type of organization that is emerging. The network and virtual organizations he describes can be called Service Supply Chains. He explains:

> "These companies could be called network organizations as they consist of a web of relationships. The virtual corporation is another designation that is becoming increasingly frequent. ... This is the beginning of a new type of firm where the future possibilities of IT have only just begun to be exploited. ... Its strength is the ability to combine its own resources with resources from other organizations

> and its ability to grow and shrink more quickly than the traditional organization. ... In order to exist in the long term, a network organization must have a "heart," a core of competence. This core is usually associated with a unique product or service, an ability to innovate, a unique marketing method or a financial strength. From that core, a texture of alliances and contacts can be woven and the boundaries of the organization fade away into thinner shades of grey and merge with other organizations. ... The network and virtual organization paradigm will grow in importance for service management. Or rather, its development is intertwined with new approaches to service management and applications of the service paradigm." (Gummesson, 1994)

Sampson (2000) explores the customer-supplier duality as it pertains to supply chain management, including practical and managerial implications. The author states that in service organizations, one of the primary suppliers of process inputs is customers themselves, who provide their bodies, minds, belongings, or information as inputs to the service processes. He calls this concept "customer-supplier duality." Because of this duality, the author considers Service Supply Chains as bidirectional, which is that production flows in both directions. The article's purpose is to explore the uniqueness of services as it pertains to supply chain management concepts. Services are "intangible products" and, may be difficult to store, it can be difficult to account for, and it could be difficult to identify their supplier. When analyzing definitions based on inputs and outputs of services, he concludes that all services act on something that is provided by the customer. All services have customers as the primary suppliers of inputs. Therefore, major portions of production cannot begin until customers have supplied their inputs.

Anderson and Morrice (2000) propose a simulation game designed to teach service oriented supply chain management principles. They acknowledge that Service Supply Chains behave differently from finished goods inventory distribution chains. In particular, Service Supply Chains do not have inventory stocks that are replenished directly through order placements, but rather only backlogs that are managed indirectly through service capacity adjustments.

They developed a game is called the Mortgage Service Game. When each stage of the process is managed by a separate company and control its own capacity, a problem emerges because each company only sees its own backlog when making the decision, not the global new application rate nor other stages backlog. The importance of this article is the simulation of service related condition in supply chain management, including an interesting mathematical formulation. The same authors also wrote an article about capacity and backlog management in queuing-based supply chains (Anderson et al., 2002) where they developed a two-stage serial capacity management model to investigate the dynamic behavior of service oriented supply chains. Each stage holds no finished goods inventory, but only backlogs that can be managed solely by adjusting capacity. They developed optimal control policies for both stages that trade off backlog cost against capacity adjustment cost when information is shared. They acknowledge that little research exist on managing supply chain dynamics in the absence of finished goods inventory.

According to the authors, this paper is different from related work in the job shop literature because, they (1) focus on issues more relevant to Service Supply Chains rather than job shops, particularly the effect of one stage's policy upon other stages' performance, (2) assume a capacity constraint and a cost associated with changing capacity, and (3) develop an optimal rather than heuristic control policy.

The same authors also developed a two stage serial staffing model and compared the benefits of sharing backlog information under centralized and decentralized control.

(Anderson et al., 2005, 2006). These articles are of major importance because they develop system dynamics models to describe the behavior of service oriented supply chains. These models lead to interesting conclusions and can be a basis for further models. However, while they developed simulation models, integer programming models are presented in this dissertation.

The term Service Supply Chain has also been used in a different context, de Waart (2004) defines it "as all processes and activities involved in the planning, movement, and repair of materials to enable after-sales support of the company's products." This definition is presented for informative purposes but it is not the way Service Supply Chain is defined in this dissertation.

## 2.6 Differences between Service Supply Chains and Physical Inventory Supply Chains

The Supply Chain Management concepts and ideas have traditionally been associated with the logistics and transportation of manufactured goods between different stages of the chain from raw material to the final customer. The service industry (and especially information-based services) presents particular characteristics that impede the direct application of the current body of knowledge. Among these differences are:

A) **The customer is a participant in the Service Supply Chain**: in Service Supply Chains, the tangible and intangible elements of services are directed towards the customer and his/her possessions, intellect, assets, or information. There are flows in both directions between the consumer and the service providers. One of the most relevant implications is that major portions of the service delivery process cannot begin until customers have supplied their input (Sampson, 2000).

Since the customer represents the first link in the chain, it is important to establish effective ways of receiving the inputs that he provides. If the customer is going to be physically present, the design of the facilities should assist the reception of customers' input, and the communication with the customer should be structured to capture effectively all the inputs needed and deliver the product effectively. Because customers are participants in the service processes, their knowledge, experience, motivation, and honesty affect the interaction with the service providers and the Service Supply Chain. The characteristics and quality of the experience while interacting with the provider influence the customer's perception of quality.

B) **The Service Supply Chain delivers an intangible output**: Some Service Supply Chains might have no tangible output; others might have a mix of physical output and intangible output. When a customer buys a manufactured product, she is able to see, feel, and test it before committing to buy. On the other hand, the customer cannot have that kind of experience with services. Because the flows within the Service Supply Chain involve intangibles, they are different from physical inventory supply chains and present new challenges.

C) **There are no inventories between the different tasks**: In manufacturing, inventories serve as a buffer to absorb variations in demand. In Service Supply Chain this buffer does not exist, and demand fluctuations are transmitted directly to the chain. In manufacturing, the different stages are joined by inventories of parts and goods in-process. In the SSC, the buffers between different tasks are customers or customers' belongings waiting in a queue. The inventory size equivalency is queue length.

D) **Time perishable capacity**: Because services are non-inventoriable commodities they cannot be stored for later use. Service capacity is lost forever when not used. This generates a challenge for Service Supply Chain Management that should balance capacity, facility utilization, use of idle time, and customer waiting. Service Supply Chain Management is concerned with service capacity allocation, efforts to manage demand, and the aim to provide flexible capacity that will allow a better utilization of capital.

E) **The output quality is hard to assess before delivery**: Because of the nature of the Service Supply Chain, the output can hardly be inspected and measured before delivery; it can only be assessed after the customer experiences the service. For that reason, to ensure quality, Service Supply Chain Management should focus on controlling the service delivery process and establishing effective methods of feedback and disconformities resolution. When services have already been consumed, they cannot be serviced or reworked; and services that do not meet the requirements are difficult to replace. Another challenge is that the quality of services is more dependent on subjective perception and expectations of customers.

There are several similarities between a service Job and jobs in a job-shop scheduling problem, but there are differences as well, summarized in Table 2.2.

**Table 2.2** Similarities and Differences between Service Jobs and Job Shop Schedule

| **Similarities** | |
|---|---|
| *Service Job* | *Job Shop Scheduling* |
| Task List | The sequence of machines for each job is prescribed |
| Resources | Processing Time |
| Set of service providers | Set M of machining centers |
| Jobs arriving according to a Poisson stream with rate λ | Jobs arriving according to a Poisson stream with rate λ |
| **Differences** | |
| Random number of service jobs to be processed | A set $J = \{1(1)n\}$ of jobs, which are to be processed |
| Because of the modularity assumption, the internal details of a service provider are hidden, and service providers can process several jobs at a time | A machine can process only one job at a time, and the processing of a job on a machine (operation) cannot be interrupted. |

## 2.7 Assumptions about Best Practices for Service Supply Chain

Some assumptions are made throughout this dissertation, about how the Service Supply Chain is structured. These include the existence of a chain leader, modularity, partnership between members of the chain, and the need of a balance between efficiency and responsiveness.

**Chain Leader**: From the customer point of view, the service product is assessed as a whole. The entire experience will be evaluated and a perceived quality assigned by the customer. There will be only one company responsible for good or bad quality, irrespective of how many different companies, departments or persons are involved in each task of the service delivery process, only one will be held responsible by the customer. This responsible company, whose name brand is associated with the performance of the Service Supply Chain, should be the leader of the chain. During the service delivery process, there are interactions with the customer. Even when the interaction points might be outsourced, the perception of the quality of the service depends highly on the customer experience during this interaction and the chain leader would be accountable for the experience and the results at this point.

**Modularity**: The Service Supply Chain should be designed as separate elements or modules able to work together integrated as a whole. This implies that there will be public information visible by all the modules and private information visible only by the concerned module. This concept of modularity is taken from computer architecture and it implies a set of visible design rules or visible information that defines and controls the interactions across independent organizations and hidden information within each element of the system including hidden operational and organizational information.

The leader is responsible for the service design, components of the service product that the customer experiences and the set of visible rules (architecture, interfaces, and standards) as follows:

- The leader should specify which modules are going to be part of the system and the functions they will perform (architecture).
- How the modules will interact and communicate with each other (interface).
- What are the performance measures for each module (standards) in order to assess the capability of the different vendors to provide the module and to determine how is each module performing relative to the other modules and for the Service Supply Chain as a whole.

The service provider responsible for each module might determine the hidden information of each module (design modularity) with varying degrees of independence from the leader. They will consist of the productive processes, facilities, materials, equipment, people, and organizational structure, of each element of the supply chain. Changes in the hidden information should not affect the rest of the chain as long as the visible information remains unchanged.

**Partnerships with members of the Service Supply Chain**: SSC members should not be selected only on basis of price or through a competitive bidding process. On the contrary, partnerships should be built with vendors and suppliers, which will allow their participation in the service process design and improvements, but also should share with them the rewards. Both parts should work together to determine target cost and to lower cost through the supply chain. Everybody involved in the supply chain should share the rewards and the risks. For this kind of relationship to exist all the parts involved should work towards building trust in each other, with enhanced communications and coordination as well as long term commitments that might include capital participation of the leader in the third party providers.

**Balance between efficiency and responsiveness**: According to the characteristics of the demand and cost structure of the Service Supply Chain, it is necessary to reach a balance between efficiency and responsiveness. If the variation in demand is low, efficiency is the primary concern. If the variation of the demand is high, responsiveness is important. Unlike manufacturing supply chains that use inventories to hedge variations in demand, Service Supply Chains use different resources. Setting the capacity of every element of the supply chain to satisfy peak demand represent high and inefficient costs, especially if the variation in demand is high. There are several methods to cope with variations in demand, including separating customer contact from back office operations, having an adaptive workforce and contracting capacity on demand with third party providers. For the external vendors to provide capacity on demand, they must be able, perhaps by being involved in different supply chains, to switch capacity from one job to another. As usual, consolidation reduces the effect of variation. If the third party providers are involved in different chains, especially if the chains have inverse demand patterns, they will be able to manage their capacity as needed. This flexibility will likely represent higher costs because it involves a highly skilled and flexible workforce, and information systems connected with different Service Supply Chains. However, saving during low and average demand periods compensates for the extra cost incurred during peak times.

**Visibility**: Supply and demand fluctuations should be visible to chain members. Current advances in IT allows to link systems across many companies to achieve this goal. This enables efficient collaboration between all the participants. Visibility improves efficiency and flexibility.

For the purpose of the models in this dissertation it is assumed that there is perfect information sharing among the SSC members the backlog, capacity and demand information is shared and the chain leader has centralized control over capacity decision and production planning.

## 2.8 Demand Process

Silvestro et al. (1992) propose three service categories. They are professional services, service shops and mass services:

1. Professional services are defined as organizations with relatively few transactions, highly customized, process oriented, with relatively long contact time, with most value added in the front office, where considerable judgment is applied in meeting customer needs. Examples are management consultancy and corporate banking.

2. Mass services are organizations where there are many customer transactions, involving limited contact time and little customization. The offering is predominantly product-oriented with most value being added in the back office and little judgment applied by the front office staff. Examples are retailing, wholesaling, and schools. Because mass services allow a high degree of customization and value added in the back office, major portions of the service might begin before the customer's input.

3. Service shop is a categorization that falls between professional and mass services with the levels of the classification dimensions falling between the other two extremes. Examples are hospitals, and auto repairs.

It is important to emphasize that it is hard to smooth production, because service cannot be stored in inventory. Usually the service delivery system needs to be ready when the customer demands it or there will be no service delivery. Forecasting demand for services present the same or higher level of complexity than for manufacturing industries. Here are some examples taken from the annual reports of some service providers:

- E-Loan: "The mortgage banking industry is generally subject to seasonal trends. These seasonal trends reflect patterns in the national housing market. Home sales typically rise during the spring and summer seasons and decline during the fall and winter seasons. The effect of this seasonality is muted to the extent of mortgage refinancing activity, which is primarily driven by prevailing mortgage rates. In addition, mortgage delinquency rates typically rise temporarily in the winter months driven by mortgagor payment patterns." ("FORM 10-K For the fiscal year ended April 1, 2004," 2004)

- AMC ENTERTAINMENT INC: "Our revenues are dependent upon the timing of motion picture releases by distributors. The most marketable motion pictures are usually released during the summer and the year-end holiday seasons. Therefore, our business can be seasonal, with higher attendance and revenues generally occurring during the summer months and holiday seasons. Our results of operations may vary significantly from quarter to quarter." ("FORM 10-K For the fiscal year ended December 31, 2003," 2004b)

- INSWEB CORP: "InsWeb operates an online insurance marketplace that enables consumers to shop online for a variety of insurance products, including automobile and term life, and obtain insurance company-sponsored quotes for actual coverage. In order to create this marketplace, InsWeb has established close relationships with a significant number of insurance companies throughout the United States....Seasonality affecting insurance shopping and Internet usage may cause fluctuations in our operating results...We have experienced seasonality in our business associated with general slowness in the insurance industry during the year-end holiday period. We expect to continue to experience seasonality as our business matures. Because of this seasonality, investors may not be able to predict our annual operating results based on a quarter-to-quarter comparison of our operating results. We believe seasonality will have an ongoing impact on our business." ("FORM 10-K For the fiscal year ended December 31, 2003," 2004a)

Russell presents the case of Disney's planning process "Disney's ... Demand is highly seasonal and varies by month and day of the week. Economic conditions affect annual plans, as do history and holidays, school calendars, societal behavior, and sales promotion." (Russell et al., 2002)

Different aspects of the demand need to be forecasted using geographic distribution, service type and service volume. Heizer highlights that forecasting in the service sector presents unusual challenges as:

- special need for short term records,
- needs differ greatly as function of industry and product,
- issues of holidays and calendar,
- unusual events. (Heizer et al., 2004)

## 2.9 Classical Production Planning Models

There is extensive research on production planning models for the manufacturing industries. The objective of this dissertation is to build on those models and adapt them to the particular characteristics and needs of the service sector. A good example is the variable workforce model presented by Hax and Candea (1984) "Production planning is concerned with the determination of production, inventory, and workforce levels to meet fluctuating demand requirements."

They explain that the variable workforce model could be applied:

> "Whenever it is feasible to change the workforce during the planning horizon as a way to counteract demand fluctuations, the compositions of the workforce becomes a decision variable whose value can change by hiring and laying off personnel. Therefore, the corresponding hiring and layoff cost should be part of the objective function. Moreover, the corresponding model presented … allows for shortages to be included; thus a backordering cost is also part of the formulation".

They present linear cost models divided into two categories:

- Classical linear programming: "where the objective function represents a unique goal (such as minimizing the total production cost)"
- Goal programming formulations "in which several goals appear explicitly, and tradeoff among these goals are worked out based on a set of priorities, rather than specific numerical cost factors"

A dynamic programming approach has been proposed for problems where a facility manufactures a single product to satisfy known integer demand over a finite planning horizon. Florian et al. (1980) present some algorithms and analyze the computational complexity of some problems and find that some problems are NP-hard and unlikely to be solvable in polynomial time.

Network models are also of interest for Service Supply Chains. Winston and Venkataramanan (2003) present a chapter with the basics of network models, including shortest path, maximum flow, CPM-PERT and minimum spanning tree. They also discuss minimum-cost network flow problems, of which transportation, assignments, transshipment, shortest path, maximum flow and CPM project scheduling are all special cases.

The most commonly used methodologies for solving the vendor selection problem are: total cost approach, multiple attribute utility theory, multi-objective programming, total cost of ownership, and analytic hierarchical process (Wadhwa et al., 2007) Wadhwa presents and compares several multi-objective optimization methods for solving the vendor selection problem. Yang et al. (2007) suggests a decision model for BPO adoption by AHP method. Wu et al. (2005) survey analytical tools for capacity planning in high-tech industries and explore the role of option theory and real options in modeling capacity decisions. Ren et al. (2008) Propose two contracts to coordinate both staffing levels and effort to achieve quality, they model the call center as a G/G/s queue with customer abandonment.

## 2.10 Conclusion

Services have specific characteristics that differentiate them from manufacturing. This presents a special challenge when trying to apply mathematical models, concepts, and techniques that were developed for the manufacturing industry. However, adapting some of this knowledge, in this case supply chain management, to services could result in performance improvements.

Traditional performance measures for the service industry are mostly marketing and customer centered with a strong emphasis in the functional quality and customer perceived quality. Service Supply Chains Management is proposed here as a way to improve productivity in the service sector, by reducing the total cost of producing a service.

Hierarchical production planning approaches are widely accepted in the manufacturing sector. This approach will be followed when studying the decision-making problems of Service Supply Chains.

There are some papers dealing with how to apply supply chain management to services, but they are in some cases too general and still centered in manufacturing specific problems, like inventory management. Anderson and Morrice (2000) have developed simulation-based models. This dissertation presents mathematical programming models that will provide optimum solutions under the conditions (and expected conditions) of the decision making problems.

Classical production planning models cannot be applied directly to the service industry. Therefore, new mathematical models (derived and adapted from the manufacturing based ones) are necessary to support scientific decision making in the service industry.

Several authors highlight the need for increased research. The proportion of manuscripts in the field of operations management dedicated to services has been estimated at to be between 3% and 7.5%. (Anderson et al., 2005; Ellram et al., 2007; Metters et al., 2007)

# CHAPTER 3

# SERVICE SUPPLY CHAIN DECISION STRUCTURE

This chapter presents the results pertaining to the first research objective, which is to develop a hierarchical framework for the modeling and analysis of Service Supply Chains. First, the existing service industry practices will be reviewed and examples of existing SSCs presented. Then, key entities and performance measures will be identified. Finally, a hierarchical decision system will be developed.

From a review of existing SSC practice, relevant key entities, and performance measures were identified. Typically, the primary company will describe the service product and request for bids from vendor companies or its internal units (classical outsourcing), Bids can be for part or the entire service product, and specify several cost elements. Then, using a combination of structured and unstructured methods, the primary company will make two sets of sequential decisions. The first, involve the setup of the SSC, while the second involve the periodic realignment of labor resources at the service provider site.

Supply chain management has been extensively researched for physical inventory based industries where the supply chain is a network of companies involved in the manufacturing of a product. While the service sector is structurally different from manufacturing, technological advances and competitive pressure are pushing service providers towards a network delivery system. The expectation is that these service networks will have similar benefits from those seen in the manufacturing sector. These networks are defined as Service Supply Chains. This chapter presents the hierarchical framework to study Service Supply Chains, including the definition, differences from physical inventory counterparts, and the key entities. A hierarchical decision level approach is sued to optimize the Service Supply Chain by reducing cost. This decision model includes both strategic and tactical levels.

## 3.1 Defining Service Supply Chain

A Service Supply Chain (SSC) is defined as a network of service provider facilities that deliver a set of service products. Each facility is able to process one or more service tasks on an as needed basis. These facilities may be outsourced or owned by the primary company, and are often located in multiple geographies to exploit local cost advantages and expertise. Demand for the service products is variable and the SSCs adjust capacity to demand requirements.

Following the definition of a service package by Fitzsimmons and Fitzsimmons (2004), a SSC is a group of providers that together form a delivery process for a set of specific service products. The processing of each service product is divided into several tasks. The tasks may be performed in series, in parallel or in a combination of series and parallel arrangements. Each provider performs one or more tasks in the delivery process. Between these providers, there are material, information, and financial flows. Because of the intangible and perishable characteristics of services, there is no inventory between the different tasks to decouple the stages in the service process. Instead, customer waiting serves as the buffer between the different tasks, either in the form of the customer's physical presence while waiting, or by queuing the customer belongings upon which the service is being performed. Figure 3.1 is a schematic representation of a service product delivered by a SSC. From a review of existing SSC practice, the following key entities were identified:

**Service Product**: a definable service offered to the market, with a specific start and end. Between the start and end the SSC will process several decisions and/or actions. Examples of service products are: (i) a mortgage approval process, which starts with the submission of an application and ends with an approval decision, (ii) a medical post surgical rehabilitation starts with a physician prescription and ends with the patient's release. Some characteristics of service products are:

- The service product is divisible into a series of tasks in a converging tree structure.
- The service tasks are processed by different entities, each with a specific task related competence.
- Demand for these services is highly uncertain, making it uneconomical to maintain a permanent, dedicated service provider workforce.

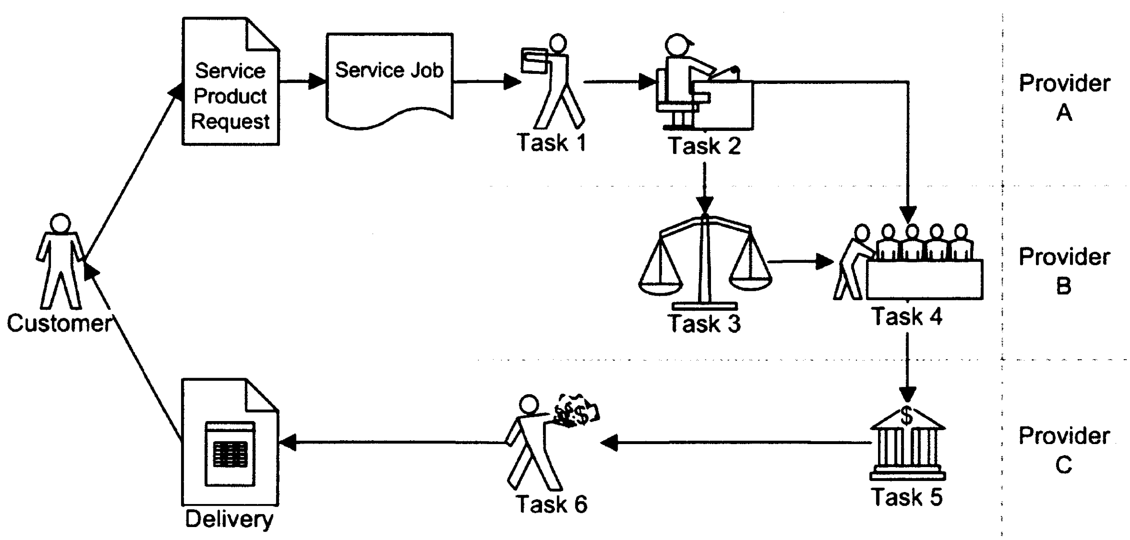



**Figure 3.1** Service product delivered by a Service Supply Chain.

**Service Job**: the sequence of tasks initiated with a customer request for a specific service product and terminated with the delivery of the product. Each customer request generates a service job.

**Service Task**: a definable process that generates part of the service product. This process is initiated by the completion of one or more precedent tasks and has an end that is unambiguous. The characteristics of service tasks are:

- Processed by a labor resource.
- Tasks waiting to be processed can be queued.

**Service Provider**: entity responsible for performing one or more service tasks. They possess a specific task related competence relevant to the service being delivered. Each service provider is autonomous has its own supporting facility, facilitating goods and personnel to perform a service task. However, they are coordinated with the SSC.

**Demand Behavior**: A main driver for the creation and configuration of Service Supply Chains is the demand variability. When demand is constant, some parts of the service may be subcontracted but there are no pressures to manage costs derived from changes in capacity. For example, a company might subcontract the janitor services to keep its buildings clean. A janitor has the capacity to cover a certain number of square feet per unit time. As a result, the total capacity required is related to the number and size of the buildings, which is not likely to change abruptly and it could be considered constant. This is not a SSC.

On the other hand, demand can be variable—either seasonal, growing because of strategic positioning or subject to business cycles and other macroeconomic factors. In these situations, a better approach is to manage capacity and chain configuration according to different levels of demand. The need to adapt the service delivery system to changes in demand creates the problems that Service Supply Chain Management addresses.

The operating objective of a SSC is to achieve sustainable competitive advantage through responsiveness, efficiency, and lower cost. Service supply chain management (SSCM) is the science of adapting the organization, configuration, and capacity of the service delivery process according to demand variability, and establishing a network with the best resources and service providers to deliver a service that satisfies customers' expectations of quality. Figure 3.2 represents a SSC. The service delivery process is divided into tasks performed by separate service providers, establishing a network of persons, departments or companies—each responsible for one or more tasks.

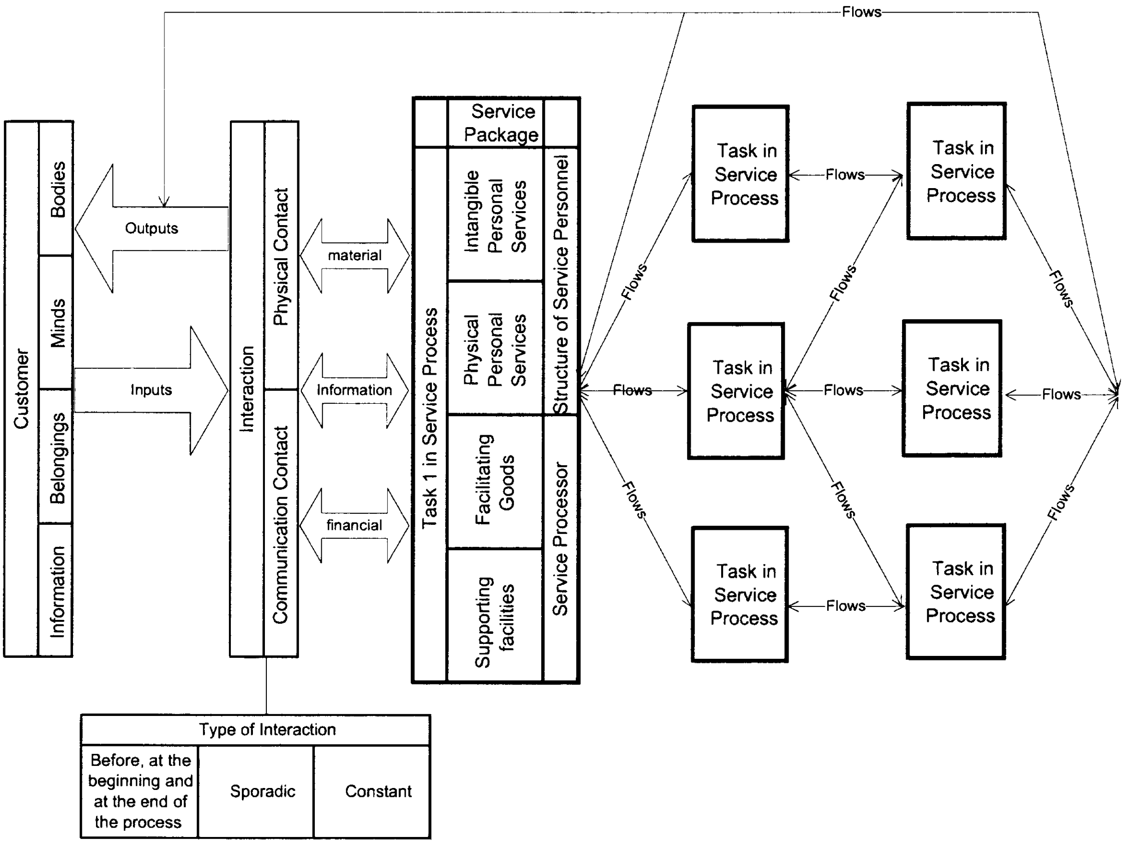



**Figure 3.2** Generic Service Supply Chain.

Within a service delivery system, there may be material flows (facilitating goods, raw materials). However, the behavior of these flows and the problems associated with them are addressed by physical inventory based supply chain theory. The main goals regarding physical flows are inventory reduction and JIT inventory management. This dissertation is not concerned with facilitating goods' flows. Instead, it studies information intensive services, their configuration, and capacity management.

## 3.2 Motivation for Managing a Service Supply Chain

Karmarkar et al. (2007) estimate that the information service sector comprises more than 50% of the private economy in the US, and is growing. Simultaneously, technological innovations like workflow platforms allow the division of the service delivery process into tasks. These tasks can be performed by different entities at a lower cost or with better quality, allowing service providers to strengthen and expand core competencies. Advances in information technology, workflow platforms, and their integration are relatively new phenomena (late 1990's early 2000's) that create challenges and opportunities for the service industry.

Service providers face the problem of changing customer demand and the need to respond quickly to those changes. When demand is higher than the available capacity, the customer joins a queue. As a result, delivery time is increased and customer perception of quality is negatively affected. A possible solution is to provide enough capacity to cover the maximum expected demand. Unfortunately, this capacity is underutilized when demand is not at its highest point. To increase capacity, service providers incur capital expenses—and capital is a scarce resource. Some tools applied when facing variable demand are sales intelligence, accurate forecasting, flexible workforce, flexible facilities and outsourcing.

An organization may opt to build fixed resources and a permanent service delivery process. Such an arrangement provides benefits such as quality control and process control. The premise here is that in many situations this arrangement is not viable either economically or operationally. In such situations, the preferred option would be to set up a Service Supply Chain. A SSC offers flexible capacity that would be available when needed. This solution aims to reduce the economic impact of both customer waiting time, and capital expenses, reducing costs across the chain.

The key motivation for a company to setup a SSC is to decrease their labor costs by the increased labor flexibility of the service provider network (lower hiring and firing costs). Some conditions that drive this motivation are:

- The demand for a specific customer service product is highly variant with large shifts, and as a result, rapid changes in processing capacity are needed to maintain a target service delay.
- The service tasks require a wide range of expertise. Often, individual expertise is shared with other industries, and hence, is best accessed from a service provider that is focused on the expertise.
- Capital constraints limit the ability to either build or develop the process capability required to perform the service task.

## 3.3 Key Entities of the Service Supply Chain

Different entities constitute the SSC: service products, service jobs, service providers, and demand variability. Section 3.1 provided short definitions for these entities, which are discussed in detail in the following sections.

### 3.3.1 Service Products

James Fitzsimmons (2004) defines service as a time perishable, intangible experience performed for a customer who is acting as co-producer. The Service Supply Chain offers different service products. For example, a mortgage broker offers different types of mortgages (fixed rate, variable rate, no private insurance mortgage, etc.). Lovelock (1983) and Sampson (2000) describe how all services can be classified into one or more of four categories:

- Services that act on people's minds (e.g., education, entertainment, counceling);
- Services that act on people's bodies (e.g., transportation, lodging, funeral services);
- Services that act on people's belongings (e.g., landscaping, dry cleaning, repair);
- Services that act on people's information (e.g., insurance, investment, legal services).

Two characteristics of service products that are of special relevance to this dissertation are divisibility and information content:

**Divisibility**: the capacity of a service product to be divided into smaller tasks. Divisibility can be represented as a continuous segment. In one extreme, some services are difficult to divide into smaller tasks that can be performed by different service providers; for example, a haircut, filling a small dental cavity, completing tax form 1040-EZ. On the other extreme of the segment are services that can be divided into several small tasks, like processing an insurance claim, processing a mortgage application, or planning a vacation. These tasks may involve different companies in the service delivery process. Figure 3.3 shows the divisible structure and associated parameters.

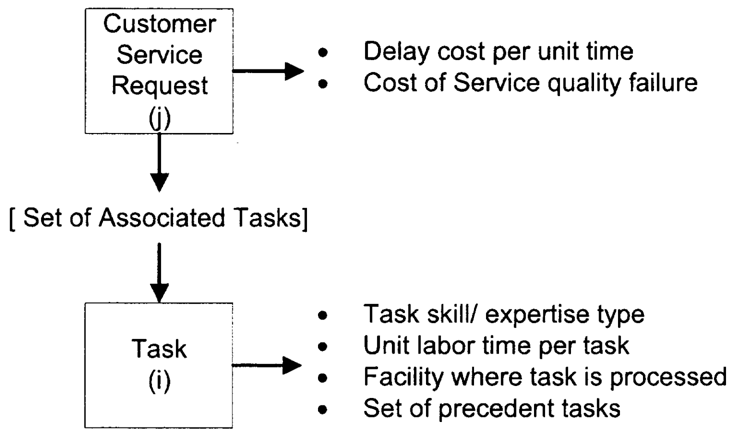



**Figure 3.3** Divisible structure and associated parameters.

**Information content**: measures the percentage of a service product that can be delivered using only information flows. The information content can be represented as a line segment. On one extreme, there are the services that process mostly the customer body or belongings, for example a haircut, scheduled car maintenance, a massage, transportation by bus, or TV repair service. On the other extreme of the segment are services that are delivered using only information flows, for example, processing a transfer from a savings to a checking account.

A plane that has as axes the divisibility and the information content (see Figure 3.4) serves as a framework for classifying services. Service products with high divisibility and high information content are the primary concern of SSCM. These services are prone to outsourcing and off-shoring—they are also highly digitizable. The efficiency frontier drawn in Figure 3.4 roughly separates the divisibility vs. information content plane into two sections. The services located between the origin and the efficiency frontier are less likely to take advantage of SSCM, because their divisibility and information content is low. The farther the service is from the origin in this plane, the more advantageous it is to use SSCM.

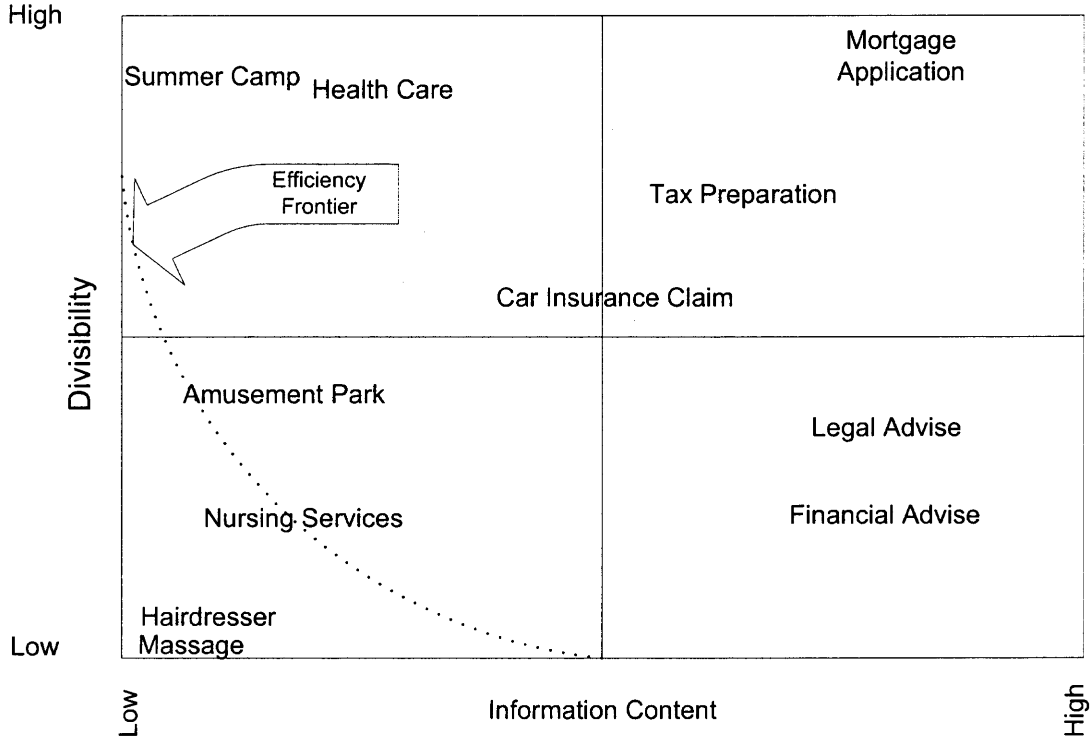



**Figure 3.4** Divisibility vs. information content plane.

Changes in technology are increasing the degree of divisibility and information flows for services. For example, telecommunications technology is changing health care services by accessing off-site databases, linking clinics or physicians' offices to central hospitals, or transmitting x-rays and other diagnostic images for examination at another site. Now, though doctors and patients may be widely separated, "telesurgery allows a surgeon at a remote site to guide and teach surgeons at a primary site by utilizing robotic devices, telecommunications, and video technology." (Bove et al., 2003)

### 3.3.2 Service Jobs

A service job is defined as an individual service product requested by a customer. The request is satisfied through a series of tasks initiated by the customer who provides input to the service delivery process. There is interaction with the customer, either through communications or through physical contact throughout the process. Figure 3.5 is a schematic representation of a service job. After the customer initiates a request for a specific service product, and therefore generates a service job, the SSC processes information, material, and financial flows to satisfy the request. The service job is divided into tasks where different service providers perform the processing and conversion of the customer's inputs. This results in the completion of the service request, and delivery of the service product.

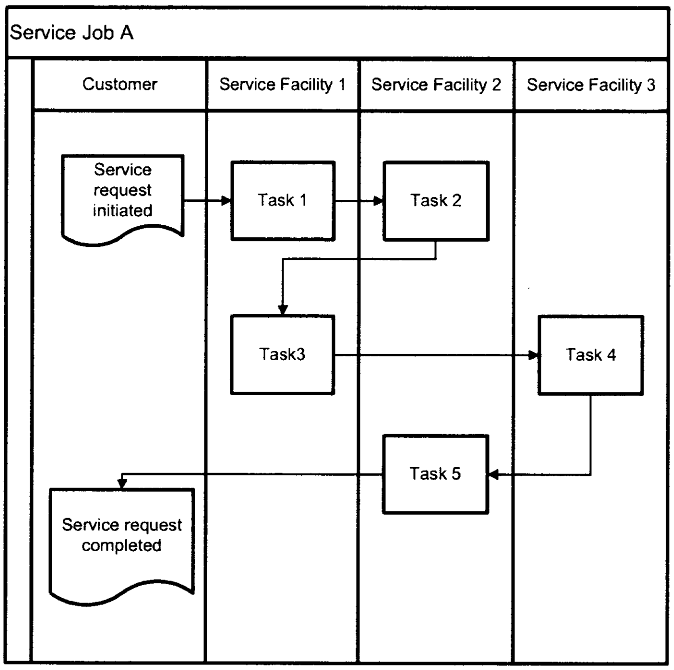



**Figure 3.5** Generic service job.

Some metrics that characterize service jobs are:

- Task list: the different steps and processes that need to be performed to fulfill the customer requirements. The task list defines precedence restrictions in the ordering of the tasks.
- Resources: time, supporting facilities, facilitating goods and personnel that are used at each task of the service delivery process to complete the service job.
- Revenue: the price paid by the customer to the service provider for the service job.

### 3.3.3 Service providers

Each service provider has a supporting facility, facilitating goods and personnel. A service provider may be able to perform several tasks of the service delivery process or just one. Because of physical limitations, there are lower and upper capacity limits at each service provider (minimum and maximum capacity). Within those limits, variations on the available capacity result in additional cost because of the addition or subtraction of service personnel. Therefore, each service provider will have a fixed cost and a variable cost. The fixed cost is a result of the investment in supporting facilities, overhead, and the minimum capacity. The variable cost is associated with capacity variation within the capacity constraints and operational costs.

Some metrics that characterize service providers are:

- Task set: the different service tasks that the provider can perform.
- Capacity: the number of service jobs that the facility can process for each task. It depends on the supporting facilities, the facilitating goods, and the structure and number of service personnel. There is a minimum and maximum capacity associated with each task at each facility.
- Capacity change cost: the cost of varying the capacity within the capacity constraints.
- Cost per server: The labor cost per unit time of each server at the facility.

- Fixed cost: The cost associated with maintaining the physical facilities, overhead cost, and minimum capacity.

## 3.4 Performance Measures

Current literature about service performance is mostly marketing and service encounter oriented (SERVQUAL, SERVPERF). This paper classifies the ten determinants of quality introduced by Parasuraman et al. (1985, 1988, 1991) according to whether they are tangible or intangible, whether they affect the technical or functional dimensions (Gronroos, 1984), and according to responsible party (Table 3.1).

**Table 3.1** Determinants of Quality Classification

| | Quantifiable | | Dimension | | Responsible | | |
|---|---|---|---|---|---|---|---|
| Deteminant | Intangibles | Tangible | Functional | Technical | Customer encounter | Service Providers | Chain Leader |
| Access | X | | X | | X | | |
| Courtesy | X | | X | | X | | |
| Communication | X | | X | | X | | |
| Credibility | X | | X | | | X | X |
| Understanding the customer | X | | X | | | X | X |
| Reliability | | X | | X | | X | |
| Responsiveness | | X | | X | | X | |
| Competence | X | X | | X | | X | X |
| Security | | X | | X | | X | X |
| Tangibles | | X | | X | | X | X |

The determinants that can be quantified and those that reflect the technical dimension of the service delivery process are identified. According to this classification, the performance measures are based on the determinants of reliability, responsiveness, and tangibles. The current marketing and customer-centered perspective has emphasized strongly the functional dimension of service quality and the customer perceived quality. SSCM offers a way to improve the technical quality dimensions of the service, allowing the SSC to adjust capacity according to demand in an economic way without compromising other determinants of quality. SSC performance is measured here by three main criteria: customer perception of quality, operational performance, and financial efficiency. These three criteria need to be balanced according to strategic goals, competition, technical advances and capabilities, financial resources, and customer expectations. This framework is only conceptual and empirical research is needed to validate it.

Based on the proposed framework for SSC performance measures, the specific challenges presented by services, and this dissertation's interests in responsiveness at the lower possible cost, some important performance measures are:

- Responsiveness: Measure of how fast the service chain can adjust its capacity to fulfill demand.
- Time to fulfill the request: How long does the service delivery system take to fulfill the customer request?
- Service cycle time: Sum of the processing time for each task.
- Financial efficiency: Revenues, labor cost, cost of resources, and productivity.

**Responsiveness**: Because services cannot be stored, the SSC either has the capacity to process the customer service request immediately or it does not, and the customer should wait. At the same time, capacity is lost forever when not used. These, coupled with highly variant demand and limited financial resources, are motivations for capacity management. Responsiveness is measured by using the hiring/firing response time and hiring/firing cost to reflect how quickly the Service Supply Chain can adjust to changes in demand, and what the financial implications are.

**Time to fulfill the request**: The customer expects the service to be delivered every time, and on time. The time it takes to fulfill the requirement is a main determinant of the customer's perception of quality. Considering the service delivery process as a chain of tasks, the service cycle time is the time between the service request and the service delivery with all the tasks performed in between (Figure 3.6). The service cycle time is the sum of each individual task time, and each individual task time is the sum of delivery time, queue time and process time.

- Delivery time is measured by how long it takes to ship task *i*-1 output to task *i*.
- Queue time is determined by the process capacity of the provider at the time of the request.
- Process time is determined by the processing efficiency of the provider.

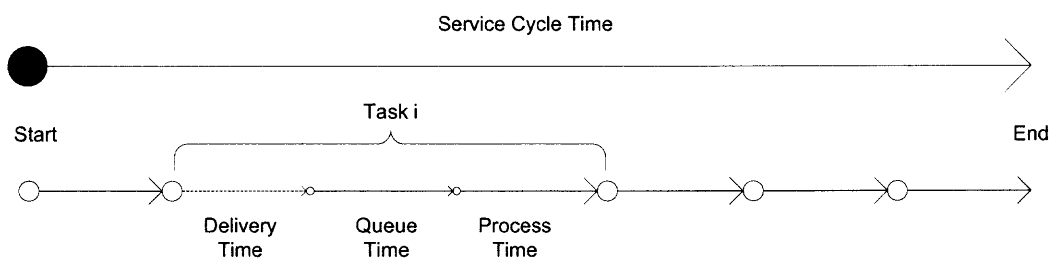



**Figure 3.6** Service cycle time.

**Financial efficiency**: Service supply chains face the challenge of delivering a quality product in a responsive and reliable way at a lower cost. The financial elements considered in this dissertation are revenues, operational cost, and the cost of resources. Market forces and demand for services at a given price determine revenues. In information intensive services, labor costs are an important component of total cost. They are the primary concern of this dissertation. The operational cost has three components, labor cost, hiring cost, and firing cost:

- Labor cost: expressed as wages per unit time. It varies proportionally with the wages per employee and the number of employees.
- Hiring cost: the hiring cost is proportional to the cost of searching, hiring, and training per employee, and the number of employees hired per period.
- Firing cost: is comprised of severance payments, legal or punitive payments, fines and taxes (if applicable). It is directly proportional to the firing cost per employee and number of employees fired.

Additionally, the main resource in services with high information content is the infrastructure required to perform the service. This is a capital investment cost. It covers buildings, furniture, communications infrastructure, and equipment.

In the literature (Gronroos et al., 2004), the following measures for service productivity are found:

$$Service\ Productivity = \frac{revenues\ from\ a\ given\ service}{cost\ of\ producing\ this\ service} \tag{3.1}$$

$$Service\ Productivity = \frac{total\ revenue}{total\ cost} \tag{3.2}$$

The revenue is controlled by market forces (demand and how much customers are willing to pay). To increase productivity SSCs focus on the cost part of the equation. The cost should be managed in a way that allows the chain to adjust capacity according to demand, while delivering a high quality service product and achieving total customer satisfaction.

## 3.5 A Hierarchical Decision Model for Service Supply Chains

The design and operation of Service Supply Chains involve capital expending decisions like contracting capacity from potential service providers and operational decisions such as adjusting capacity on a real time basis to optimize the operational cost. Classical literature in hierarchical decision models places the capital-intensive cost decisions at the strategic level and the allocation of resources (in this case labor) at the tactical level. This dissertation follows same division. The primary costs involved can be expressed as costs for the customer and costs for the providers. There are four cost categories presented in Figure 3.7:

- Service delay cost (SD) which depends on how long the service request is delayed because of capacity constraints.
- Setup cost (CC) or the capital spending needed to build the required infrastructure,
- Operational cost (OC) associated with running the infrastructure including the capacity adjustments,
- Process efficiency (PE) the efficiency of the resources used and the cost of defective services (quality).

The overall objective is to minimize the total cost:

$$SD + CC + OC + PE \tag{3.3}$$

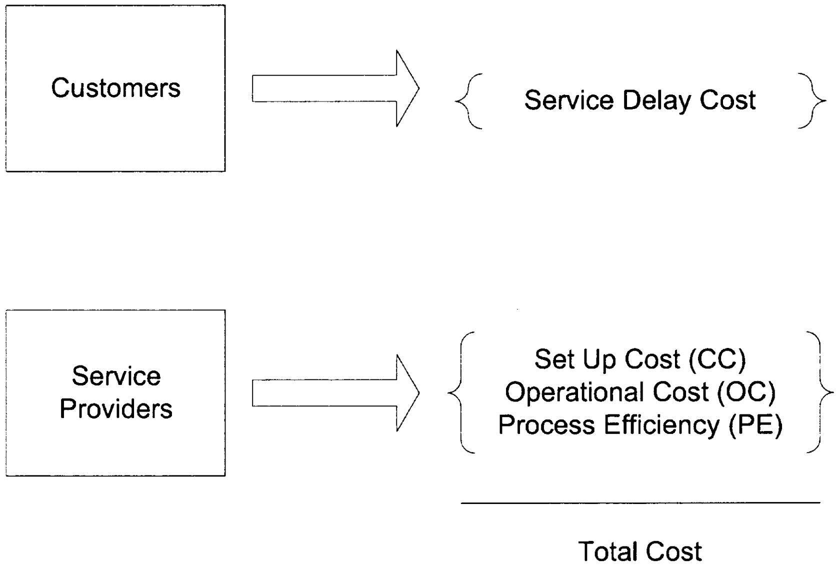



**Figure 3.7** Service Supply Chain primary costs.

The strategy for solving this problem is to divide it into a hierarchical decision making system. A classic and widely accepted framework for the decision making process was presented by Anthony in 1965. He classified decisions into three hierarchical levels: strategic planning, tactical planning, and operational control. They differ on the frequency of the decision making process and the time horizon over which the decision has an impact. Chopra and Meindl (2004) also follow this framework adapted to physical inventory supply chains. Some of the decisions required at each level are presented in Table 3.2.

**Table 3.2** Hierarchical Decision in SSC

| Level | Decisions | Objectives |
|---|---|---|
| Strategic Planning | – Product design: Number of task<br>– Number of service providers.<br>– Type of service providers: In-house, outsourced<br>– Skill level of workers<br>– Target labor cost<br>– Location<br>– Target hiring/ firing cost<br>– Facility layout<br>– Capabilities at each service provider<br>– Task assignment to each facility<br>– Target capital expenses | – Minimize Cost<br>– Strategic Positioning<br>– Maximize quality<br>– Maximize security of customers<br>– Maximize intellectual property protection<br>– Opportunities for innovation<br>– Flexibility<br>– Service Level<br>– Establish and improve relations with members of the Service Supply Chain<br>– Minimize capital risk<br>– Maximize revenue/labor cost<br>– Maximize revenue/cost of resources<br>– Maximize revenue/ capital investments<br>– Increase market share |
| Tactical Planning | – Number of servers at each facility location per unit time<br>– Man hours of regular labor<br>– Man hours of overtime<br>– Number of service tasks to be processed by each facility in each time unit<br>– Hiring/firing strategies | – Minimize Cost<br>– Complain with labor restrictions<br>– Minimize customer waiting time<br>– Satisfy demand<br>– Satisfy minimum workload constraints for each service provider<br>– Satisfy capacity constraints at each service provider<br>– Maximize revenues/number of workers in the chain |
| Operational Control | – Detailed scheduling<br>– Assignment of servers to service stations<br>– Assignment of service task to particular service provider<br>– Assignment of service jobs to particular servers.<br>– Assignment of jobs considering priorities | – Minimize cost<br>– Maximize Quality<br>– Satisfy Demand<br>– Balance workload throughout different service providers<br>– Minimize customer waiting time<br>– Minimize service delivery cycle time<br>– Maximize customers served/ cost of resources<br>– Minimize number of customers waiting<br>– Maximize % of service jobs delivered on time |

### 3.5.1 Strategic Planning

At the strategic planning level, the service provider should establish long-term goals and strategies to accomplish these goals. "During this phase, a company decides how to structure the supply chain over the next several years. It decides what the chain's configuration will be, how resources will be allocated, and what processes each stage will perform" (Chopra et al., 2004). Decisions include: the services to be offered, the location and capacity of the service providers, layout of the service facilities, and the transportation modes for the different flows (material, financial, information, and customer).

Strategic supply chain management decisions for a mortgage provider would include product diversification, low cost producer strategy, loan distribution, selection of service providers to integrate the Service Supply Chain, outsourcing, off-shoring, and interaction with the customer through phone and the internet. The time frame for these decisions is several years. In manufacturing environments, increasing capacity by adding a new plant can take years. For example, the lead time to build new capacity for biopharmaceutical companies is three to five years (Snyder, 2003). Service delivery systems with high level of information content are easier to set up, and therefore more flexible. However, contracts with members of the Service Supply Chain are in effect for several years.

### 3.5.2 Tactical Planning

The time frame for this phase is 12 to 18 months. Tactical planning decisions consider the allocation of resources to different products. The number, location, and capacity constraints of the service providers have been decided in the previous level. The process starts with quantitative and qualitative techniques to forecast product demand, including market intelligence and sales judgment factors. Of particular importance is the arrangement of supporting facilities, facilitating goods, and personnel structure to satisfy the forecasted demand. All this is accomplished within the constraints resulting from the strategic management level. When multiple service providers are able to perform the same service task, decisions are made regarding the workload at each facility.

### 3.5.3 Operational control

The time frame for operational control decisions varies, usually from one day to two weeks. This decision level covers the short-term operation of the service providers who are looking for the most profitable way to fulfill actual customer requirements. It contains all operational decisions that directly influence the flows within the Service Supply Chain. Detailed personnel schedules and facilitating goods requirements are produced as a result of the operational control decision making.

In the hierarchical system, the strategic level's objective is to minimize the setup cost (CC) and the projections of the operational cost (OC). At this level, the setup cost can be calculated with a great degree of accuracy, but the projections of the operational cost are highly aggregated and inaccurate (because of the time horizon). At the tactical level, the forecast and the cost data are more accurate. The objective at this level is to minimize the sum of the service delay (SD), operational cost (OC), and process efficiency (PE).

The SSC problem requires first to design the chain by selecting providers (minimize setup cost and projected operational cost) and then subsequently adjust capacity according to demand. It is clear that such a hierarchical approach will enforce a constraint on the strategic model. This is based on the premise that the objective coefficients are in opposition.

## 3.6 Considerations for Modeling the Service Supply Chain

To study and improve the performance of SSCs, mathematical representations of the problems presented at different decision levels should be developed. This section discusses the different parameters and variables that are needed to model each decision level are discussed.

### 3.6.1 Strategic Planning

It is necessary to consider several parameters to develop a strategic decision making model. Among them are service design (number of tasks), types of service providers, number of service providers to be considered, capabilities of the service providers, target capital expenses, and target labor cost. Since the services analyzed in this study almost exclusively involve information flows, the classical facility location problem that attempts to minimize the transportation costs does not apply.

**Service design / Number of tasks**: To deliver the service products, the process can be divided into several tasks. Work design and work measurement techniques should be used to identify the economic way of dividing the service products. This should be done while also considering qualitative issues—for example, the drawbacks resulting from having different people involved in the service delivery cycle and how it will affect accountability for the system performance. At the end of this process, service products will be described by a set of tasks to be processed with a given order of precedence.

**Types of service providers**: A decision has to be made on whether they are going to be developed in-house or outsourced, and whether they will be staffed with high or low skilled employees. These decisions will be affected by objectives such as service quality, customer safety, intellectual property protection, and flexibility.

**Number of service providers**: Given the capabilities needed for each service task, the chain leader should decide if a different service provider should perform each task or if a single service provider should perform several tasks. At the end of this decision process, a set of service providers should be defined.

**Capabilities of each service provider**: The tasks are assigned to service providers based on their abilities. The processing capacity for each task at each facility should also be established. All this is a function of the core competence of the service providers.

**Target capital expenses**: Alternatives service providers will involve different capital expenses and associated risks. High-level management should decide how much capital is going to be used for the development of the service delivery process, and the level of risk that they are going to take.

**Target labor cost**: Labor cost varies among service providers. A decision should be made to align the different labor pools available with the organization goals and objectives. This decision also involves the target hiring/ firing cost.

### 3.6.2 Tactical Planning

The main concern at this level is to manage capacity at each service provider to satisfy demand. A mathematical model is presented to address this decision. It involves the use of parameters like service rate (per server per task), labor cost (per server per task), and backlog cost, where the backlog represent the cost of the customer's (or customer's belongings) waiting. Other decision variables may include number of service tasks to be processed by each facility in each time unit.

### 3.6.3 Operational Control

In a traditional manufacturing environment, one of the main issues in operational control is inventory management. This problem does not apply to Service Supply Chains. On the other hand, issues related to operational scheduling are relevant.

### 3.6.4 Quantitative Hierarchical Decisions

With the objective of minimizing cost, two models for the strategic and tactical levels will be developed (Figure 3.8).

- Strategic problem: select the service providers (facilities) that will become part of the Service Supply Chain, assign specific tasks to those providers, and design the Service Supply Chain.
- Tactical problem: manage the workforce level to satisfy demand and reduce cost.

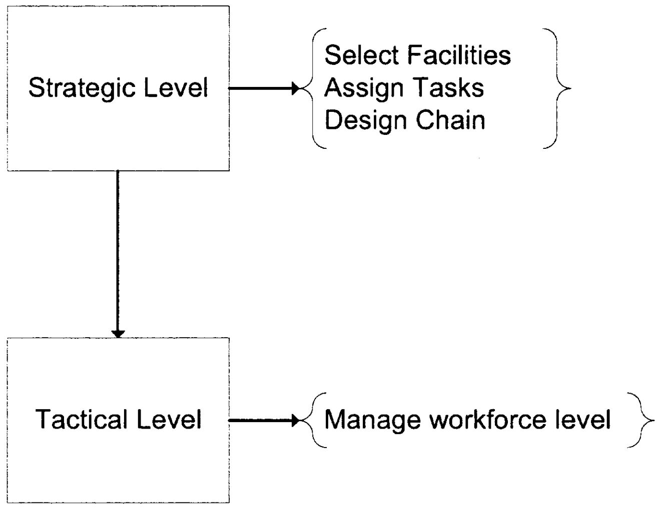



**Figure 3.8** Quantitative hierarchical decisions.

At the strategic level, the following questions need to be answered:

- Which facilities should be selected among the competing ones to become part of the Service Supply Chain?
- Which tasks will be assigned to each selected facility?

To answer these questions the following parameters and information is needed:

- What are the services to be offered?
- What tasks are necessary to complete each service?
- Which are the competing facilities?
- What is the demand behavior?
- What is the backlog cost per service?
- How many units of a particular task can an ideal server process during a single time period? (Base task rate: units per server under "normal" conditions.)
- What is the monetary value of quality?

From each competing service provider, the following information is required:

- What would be the expected quality of the tasks processed at this facility?
- What is the hiring cost, firing cost, labor cost?

- What is the expected hiring response time and firing response time?
- What is the initial investment required?
- What is the expected productivity?
- What is the maximum and minimum capacity (# servers)?
- What are the tasks that each facility is capable of performing?

It is important to remark that if a single service provider, has advantages over the competing facilities in initial cost, labor cost, flexibility and capacity, the problem is trivial because the globally efficient provider will be preferred over the competing ones.

At the tactical level, the service providers have been selected, and therefore, capacity and cost parameters are already decided. The objective at this level is to minimize cost by managing the workforce level. Solving this problem yields answers to the following questions, for each period (days or weeks) and for each service provider:

- How many servers are required at each facility?
- How many units of each task will the facilities process?
- How many servers should be hired?
- How many servers should be fired?

To get those answers, the following information is required:

- What service products are offered?
- What tasks are necessary to complete each service?
- What tasks will each facility process?
- What is the forecasted demand per period for each service product?
- What is the backlog cost per service product?
- What is the task precedence for each service product?
- What is the hiring cost, firing cost, and labor cost at each service provider?

- What is the service rate (capacity per period) per server at each facility?
- What is the maximum and minimum capacity (# servers) at each facility?

Subsequent chapters, present quantitative models to solve the strategic and tactical problems (Figure 3.9). At the strategic level, the company decides how to structure the supply chain over the next several years. It decides what the chain's configuration will be, what service providers will be selected, how tasks and resources will be allocated to each service provider. This lever requires quantification of expected demand variation, quantitative information about services to be offered and tasks to be performed, and quantitative descriptors for the service providers.

The tactical model addresses how capacity levels are adjusted (hiring & firing) to coordinate with demand variations and the production plan. It is constrained by the decisions made at the previous level. A more accurate demand forecast is available.

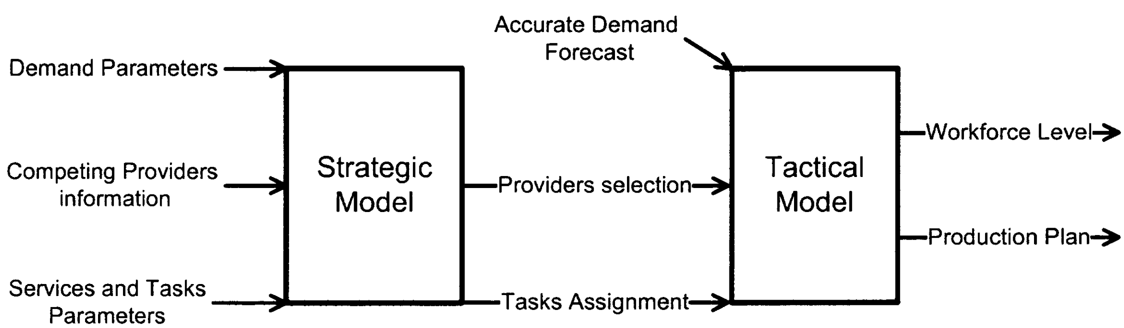



**Figure 3.9** SSCs hierarchical decision model.

### 3.7 Characterizing Demand for Service Supply Chain Modeling

The main objective of Service Supply Chain management is to adapt capacity to changes in demand. However, highly variable demand is a challenge to service providers, and forecasting presents unusual challenges in the service sector. Demand for services presents random and seasonal components, and it is correlated with other variables and conditions as the following example indicates:

- Patterns in the housing market influence mortgage products.
- Mortgage rates influence refinancing activity.
- Timing of most popular motion pictures releases influence movie ticket sales.
- Flu season influence emergency room visits.
- Hurricane season influence insurance claims.
- Holiday shopping influence retail sales.

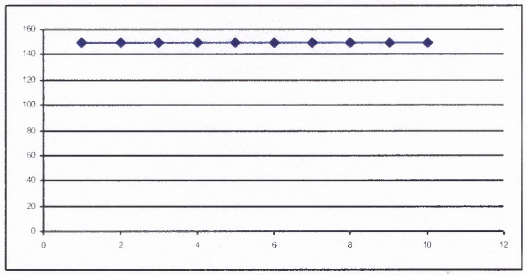
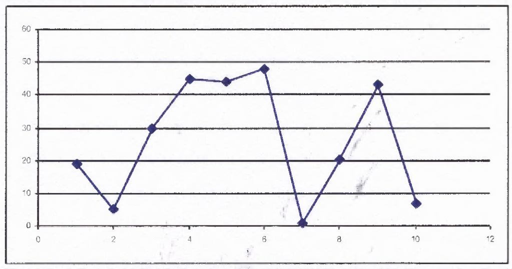
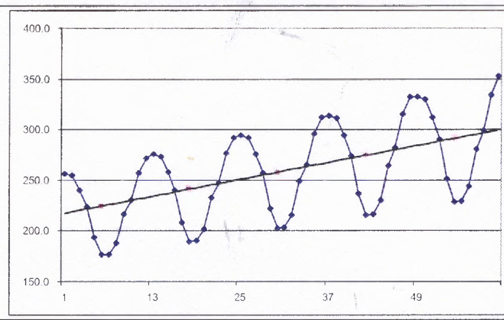
Three basic demand patterns were identified: (see Table 3.3) constant demand, completely random demand, and demand with a seasonal and trend components. Each demand pattern requires a different strategy.

**Known constant demand**: For some services, demand is fixed at a certain level. For example, In the case of janitorial services, even when the service may be sub-contracted, capacity management and adjustment is not an issue. SSC management is not required since the capacity is fixed.

**Completely random demand**: Some services face completely random demand that could be described by a probability distribution. For example, the proper strategy for a computer help desk is to fix capacity at a certain level to cover a percentage of the requests within a certain time, based on the demand distribution. Service supply chain management is not required since the capacity is fixed.

**Demand with seasonal and trend components**: Other services face demand that follows certain patterns and can be predicted to some degree using forecasting techniques. Mortgage applications are an example of this behavior. Adjusting capacity according to demand variations might result in lower costs. As an example, the behavior of the Mortgage Bankers Association's Purchase Index is presented in Figure 3.10.

**Table 3.3** Demand Patterns and Strategies

| **Demand pattern** | **Service level strategy** | **Pattern** |
|---|---|---|
| Known constant demand | Static service level |   |
| Complete random demand | Static service level to satisfy % of demand based on probability |   |
| Demand with random, seasonal and trend components | Variable service level to reduce cost |   |

The main concern of Service Supply Chain management is demand variability and how to adjust capacity to fit demand. This situation calls for demand characterization that focuses on quantifying the aggregated effect on capacity requirements (Figure 3.11).

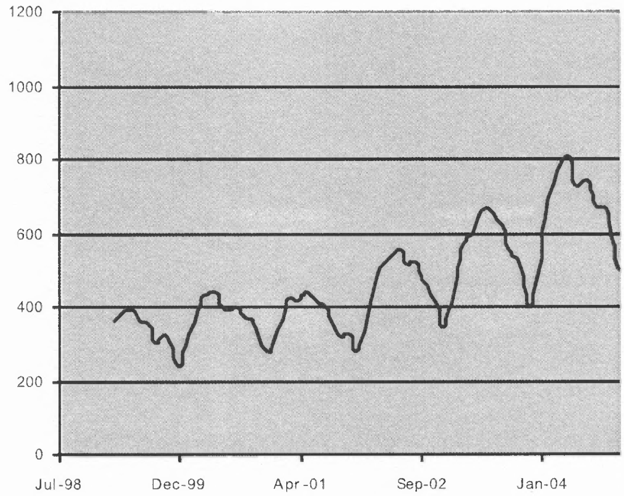



**Figure 3.10** Behavior of the Mortgage Bankers Association's Purchase Index.
Source of data: Mortgage Bankers Association "Weekly Mortgage Application Survey."

Trend and seasonal components describe the demand behavior. An equation of a line represents the trend. The mean trend demand, average range of the cyclical index, and average cycle length are the parameters used to describe the average range of demand variation. These basic dimensions describe detailed characteristics of demand:

- Minimum demand (trend)
- Maximum demand (trend)
- Mean demand (trend)
- Average range of the cyclical variation
- Average cycle length
- Expected trend range
- Expected maximum demand
- Total number of requests to be processed
- Number of cycles

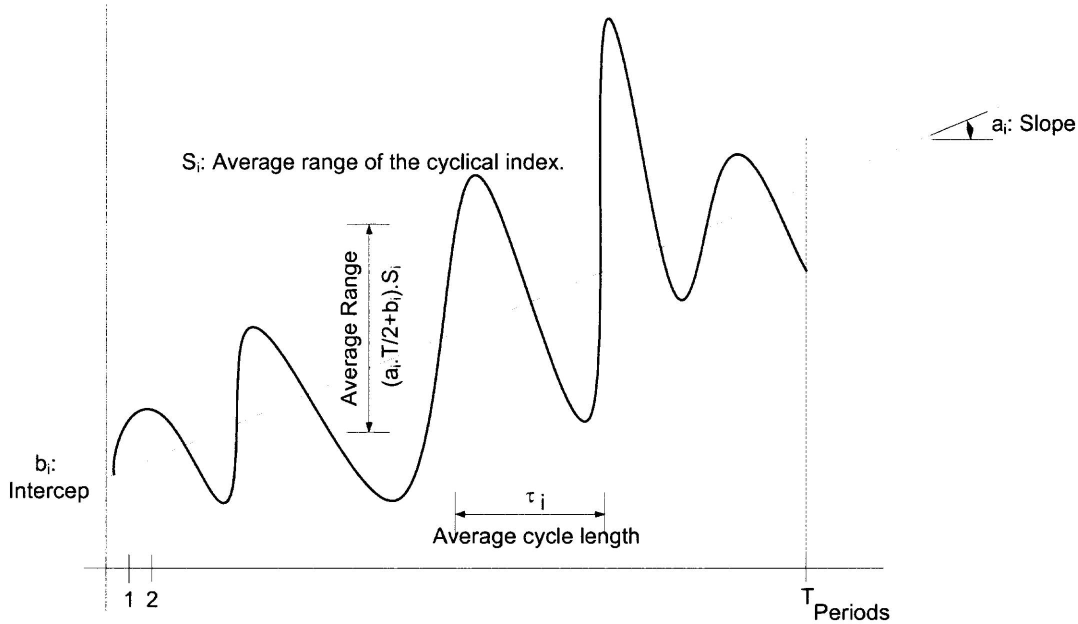
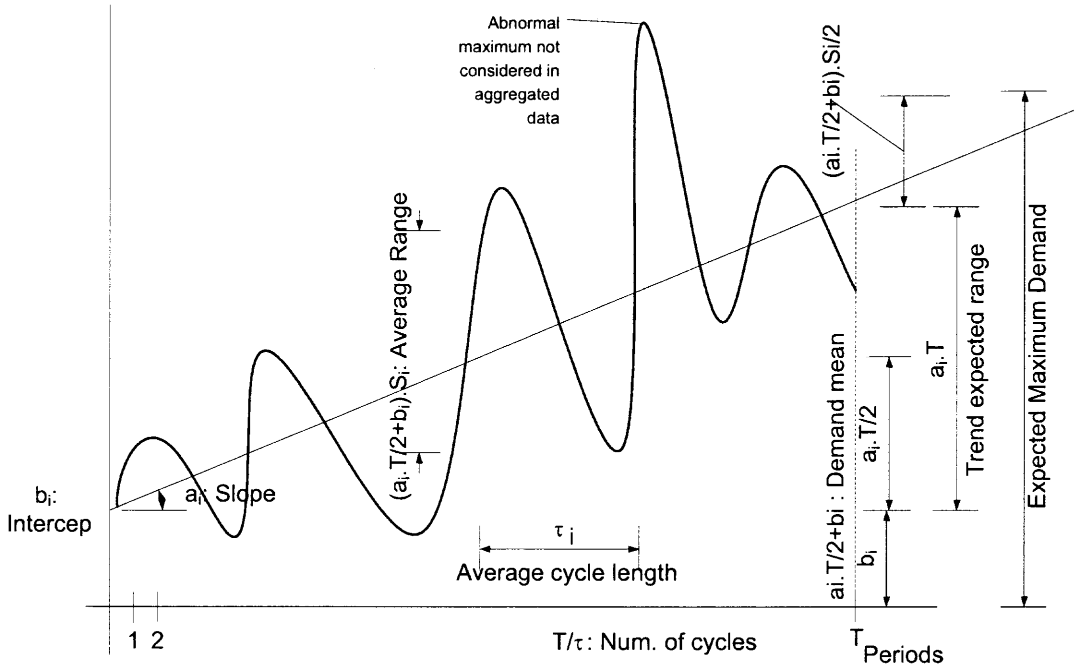



**Figure 3.11** Characteristics of demand.

These measures (Figure 3.11) allow the quantification of the aggregated variation in demand (Figure 3.12). The aggregated increase in demand is the sum of the increases in each cycle plus the increases due to the trend. The aggregated decrease in demand is the sum of the decreases in each cycle. This helps in quantifying the required capacity adjustments, the maximum capacity that the provider should have during the planning horizon, and the labor cost. Capacity requirements and costs will be modeled based on this information.




$$\frac{a_i \times T^2 + 2b_i T}{2}$$ total number of units processed

**Figure 3.12** Detailed characteristics of demand.

### 3.8 Mortgage Processing as an Example of Service Supply Chain

Mortgage processing is a product usually delivered by a Service Supply Chain. The financial sector and mortgage processing industry are highly diverse. A case was created for this study by aggregating public information available from different providers:

- AustinHomeLoan.com
- Long Mortgage Company (tucsonmortgages.com)
- Attorneys' Mortgage Services (amslawyer.com)
- The Federal Reserve Bank of Cleveland (Perspectives on credit scoring and fair mortgage lending)

- Providence Home Mortgage, Inc. Business Plan (second national business plan competition for nonprofit organizations, Yale School of Management - The Goldman Sachs Foundation Partnership on Nonprofit Ventures)
- CTX Mortgage Company (ctxmortgage.com)
- FannieMae (fanniemae.com)
- E-Loan (eloan.com)
- GreenPoint mortgage (greenpointmortgage.com)

### 3.8.1 Service Products

There is a wide variety of mortgage products. The two main types are fixed rate mortgage and adjustable rate mortgages. Other mortgage products include home purchase, home refinance, and home equity loans. E-Loan offers at least 19 different products (Figure 3.13). Mortgage processing presents the two aforementioned characteristics that are of special relevance to this dissertation—divisibility and information content.

**Divisibility**: The job of processing each application is divided into smaller tasks. Each task can be processed by different companies.

**Information content**: Only information is required to process a mortgage. The need is for information about the customer such as credit rating, employment status, and assets; information about the collateral such as value, status of the title, and whether it is being used as collateral for other mortgages; information pertaining to insurance; and information related to financial transactions.

### 3.8.2 Service Jobs

Each individual customer's application is a service job. The customer completes a mortgage application for a particular mortgage product and supplies the required documentation for processing. This is done with the assistance of a mortgage broker, on the internet or over the phone. The service product request (mortgage application) is processed through a series of tasks. The way the process is divided into tasks varies across different providers. As an example, a general model of the tasks required is presented on Figure 3.14.

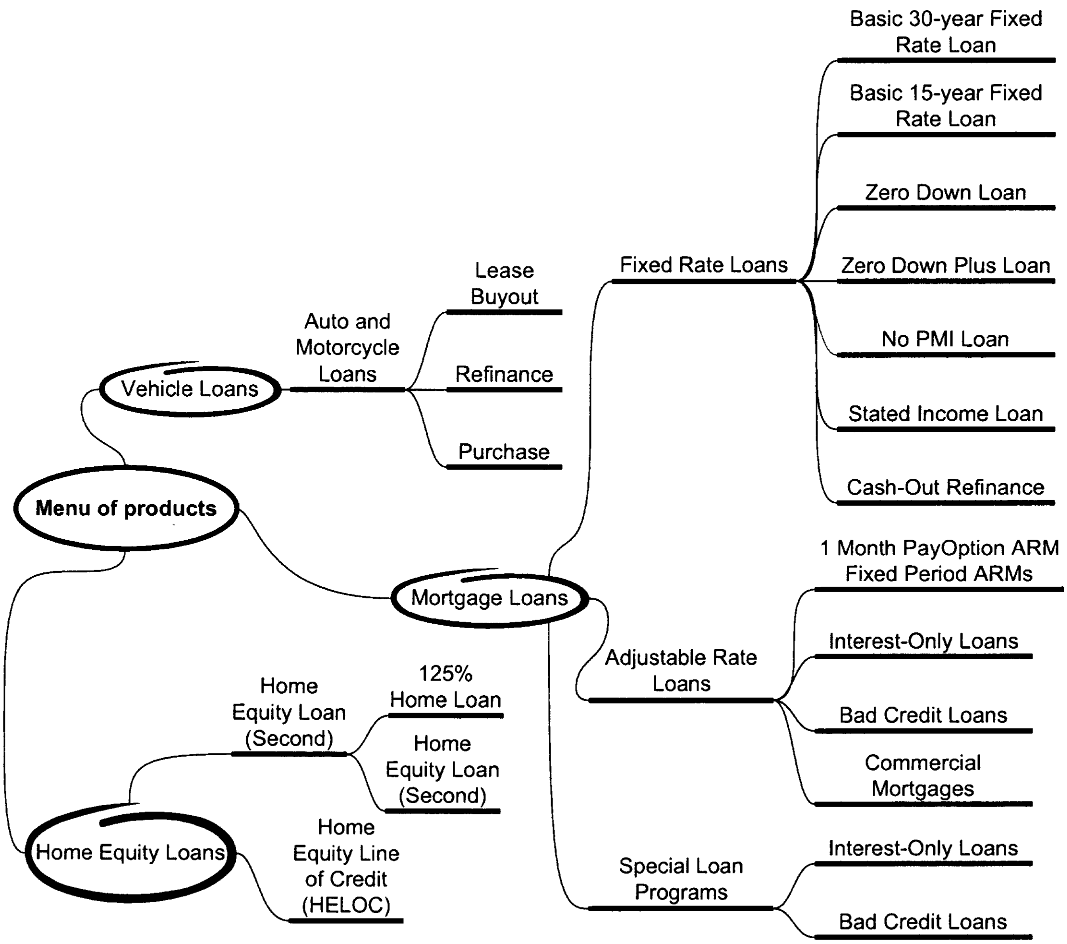
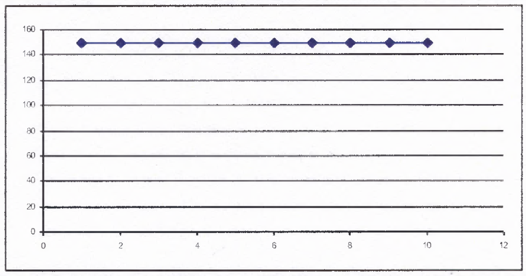
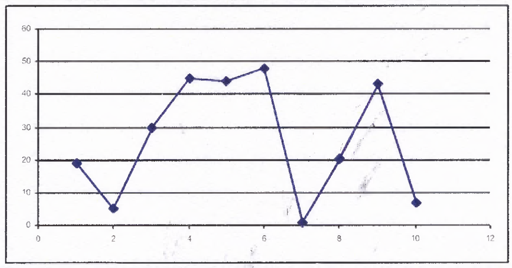
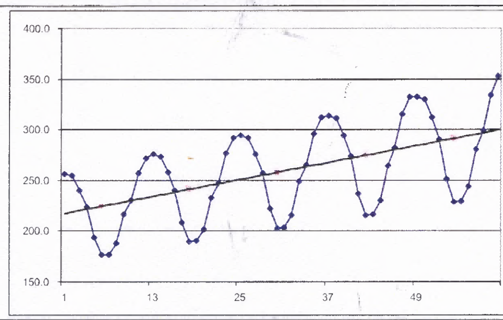



**Figure 3.13** E-Loan service products offerings.
Adapted from www.e-loan.com (8/2005).

**Demand with seasonal and trend components**: Other services face demand that follows certain patterns and can be predicted to some degree using forecasting techniques. Mortgage applications are an example of this behavior. Adjusting capacity according to demand variations might result in lower costs. As an example, the behavior of the Mortgage Bankers Association's Purchase Index is presented in Figure 3.10.

**Table 3.3** Demand Patterns and Strategies

| Demand pattern | Service level strategy | Pattern |
|---|---|---|
| Known constant demand | Static service level |  |
| Complete random demand | Static service level to satisfy % of demand based on probability |  |
| Demand with random, seasonal and trend components | Variable service level to reduce cost |  |

The main concern of Service Supply Chain management is demand variability and how to adjust capacity to fit demand. This situation calls for demand characterization that focuses on quantifying the aggregated effect on capacity requirements (Figure 3.11).

- Title companies:
  - Review title of the property
  - Receive and assemble documents.
  - Act as closing agent. (Explain documents, obtain signatures, collect, and release funds).
- Lenders:
  - Provide loan funds.
  - Make final underwriting decisions.
  - Provide servicing until the loan is sold on the secondary market.

Some financial institutions are vertically integrated and are able to provide all the services using in-house resources, but in most cases, different companies—each one specialized in its core competencies—perform different tasks during the application process.

### 3.8.4 Demand Process

The demand process for the mortgage banking industry is subject to seasonal trends. It also has a clear growth component, and it could be affected by the strategic marketing decisions of the providers and other variables such as interest rates and macroeconomic factors. To perform the numerical experiments, demand for a hypothetical firm was generated using the indexes for Purchase, Refinance, Fixed Rate Mortgages (FRM) and Adjustable Rate Mortgages (ARM) published by the Mortgage Bankers Association in the *Weekly Mortgage Application Survey* and the amount and number of loans of the top 30 national residential lenders listed in *Mortgage Banking Magazine*. The estimated demand is presented in Figures 3.15 to 3.18 and will be discussed in detail when the case study is analyzed.

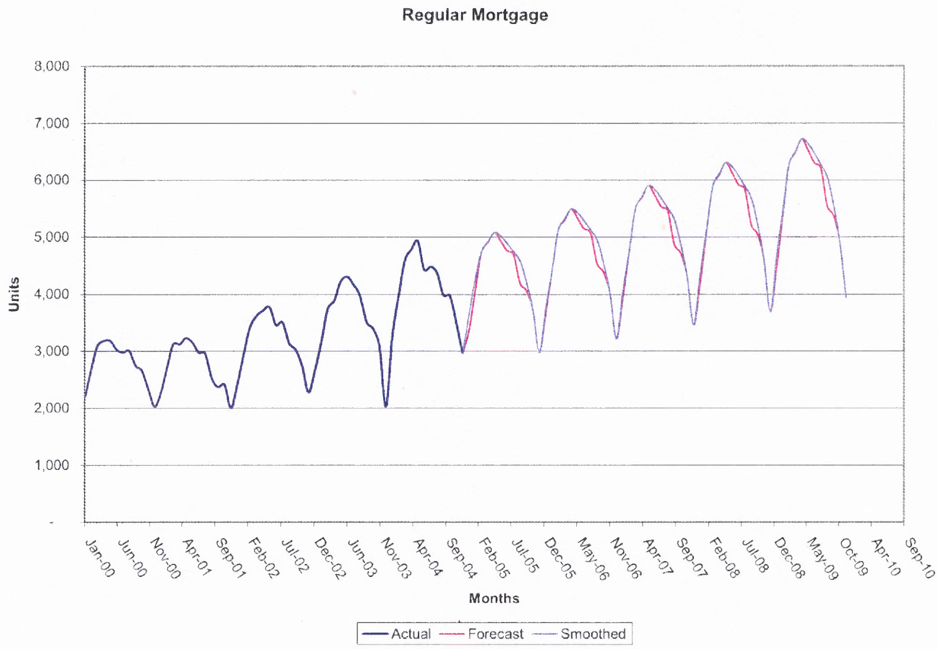



**Figure 3.15** Demand behavior for mortgages destined to purchase a property.

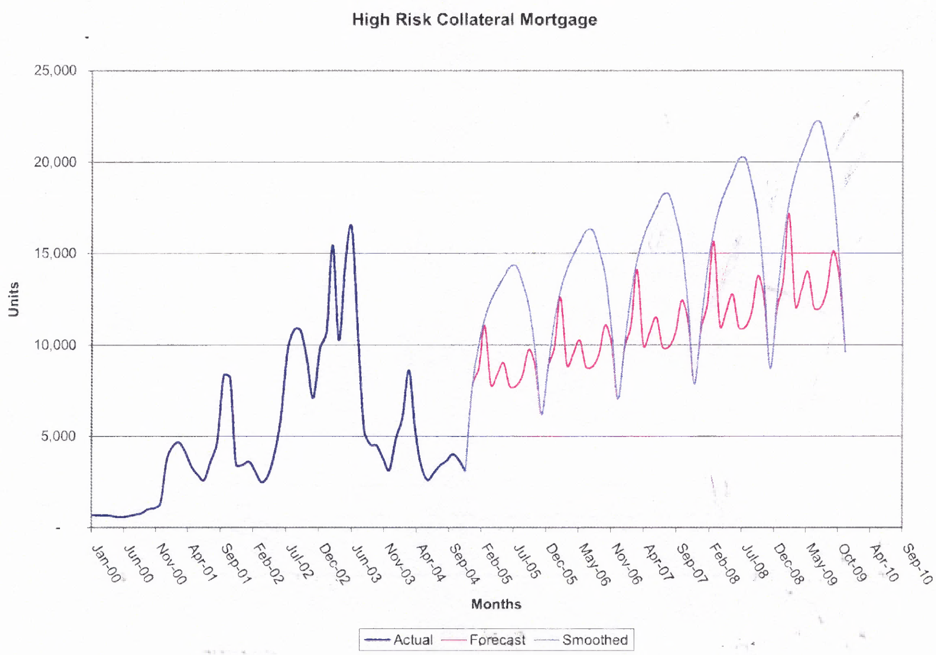



**Figure 3.16** Demand behavior for mortgages destined to refinance a property.

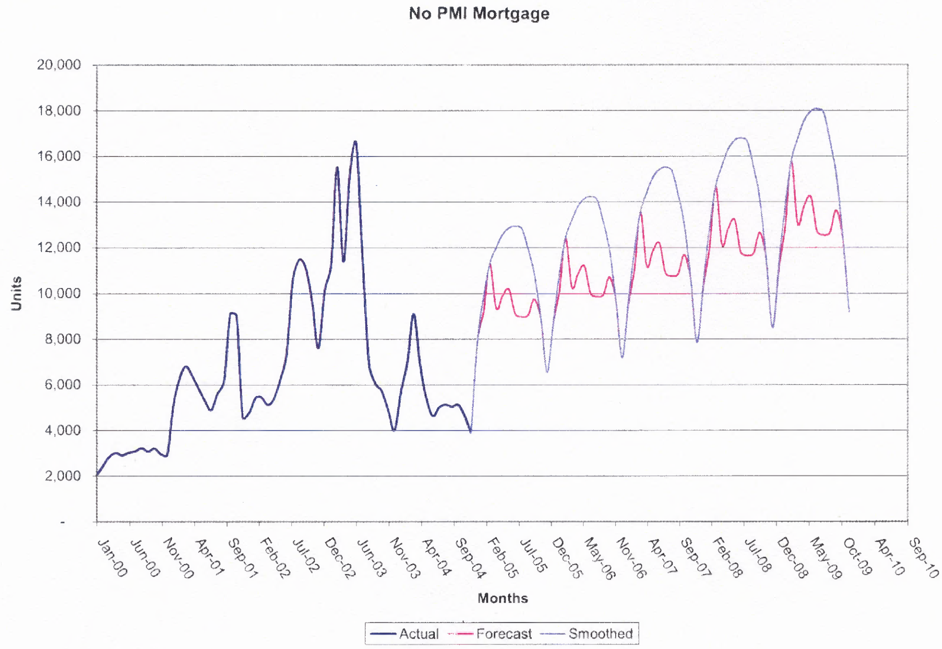



**Figure 3.17** Demand behavior for fixed rate mortgages (FRM).

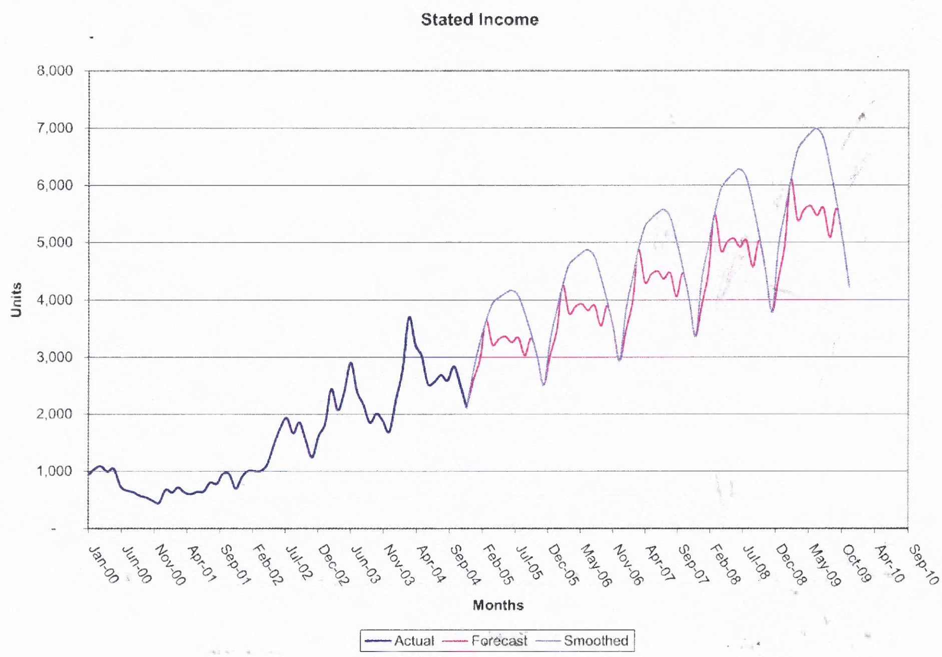



**Figure 3.18** Demand behavior for adjustable rate mortgages (ARM).

The hierarchical framework presented in this chapter provides the foundation needed to develop quantitative models for the Service Supply Chain.

# CHAPTER 4

# STRATEGIC LEVEL: SERVICE PROVIDER SELECTION AND TASK ASSIGNMENT MODEL

This chapter presents the results pertaining to research objective number two: to develop a strategic decision making model for the selection of service providers from a list of candidates, and then assign tasks within these facilities, considering the changes in demand, changes in capacity (hiring, firing), and minimizing total cost. The first task is the quantification of demand variation. The demand parameters that describe the expected demand changes are determined to quantify the impact on required capacity. The second task is to develop a strategic decision making model that selects the service providers and assigns tasks to them in a way that will minimize costs. The third task is to analyze the computational complexity of the strategic model.

At the strategic planning level, the SSC problem focuses on establishing a network of service providers to achieve long-term goals. The planning term is usually five years or more. The chain leader decides the network configuration over the next few years, the allocation of resources, and what processes each service provider will perform. A quantitative service provider selection and task assignment model is presented to assist the strategic decision-making process.

The upfront cost of selecting a particular provider could be determined with high accuracy. However, the future labor cost, the future availability of a labor pool to increase capacity, future regulations affecting labor relationships, and the demand behaviors can only be forecasted and estimated. The objective is to select the service providers that are able to adjust capacity according to demand, minimizing the total costs across the chain.

A method to estimate demand parameters and quantify variation per seasonal cycle is presented. It describes demand using growth trend and seasonality (not large business cycles). It is smoothed to describe typical demand patterns consistent with expected business conditions and strategic goals of the organization. This method considers highly aggregated demand information.

## 4.1 Quantification of Demand Variation

Demand variation is a driver for SSCM. The demand for a specific customer service product is highly variant, thus, rapid changes in processing capacity are needed. At the strategic level, demand forecasts are used to determine the parameters that quantify changes in demand. Figure 4.1 presents basic characteristics of the demand with trend and seasonal components. The following notation is used in the model formulation:

**Growth Trend**:

$a_i$: Slope of demand curve for service $i$;

$b_i$: Intercept of demand curve for service $i$;

**Seasonal Component**:

$T$: Number of periods in the planning horizon;

$S_i$: Average range of the cyclical index;

$\tau_i$: Average length of seasonal cycles.

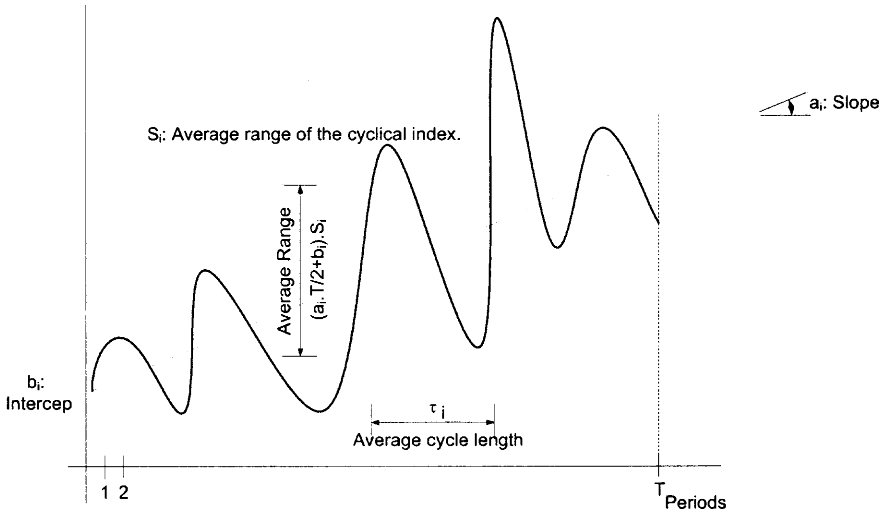



**Figure 4.1** Demand characterization.

It is necessary to quantify the cumulative demand change in either direction (positive or negative) and use it to determine the required capacity change. A single demand cycle is presented in Figure 4.2. Segments (a) and (c) represent increases in demand and segment (b), a decrease. The total increase in demand is the arithmetic sum of the length of segments (a) and (c). The length of segment (b) represents the total decrease in demand. To analyze demand, the trend and seasonality components of a single demand cycle are separated as shown in Figure 4.3 and Figure 4.4.

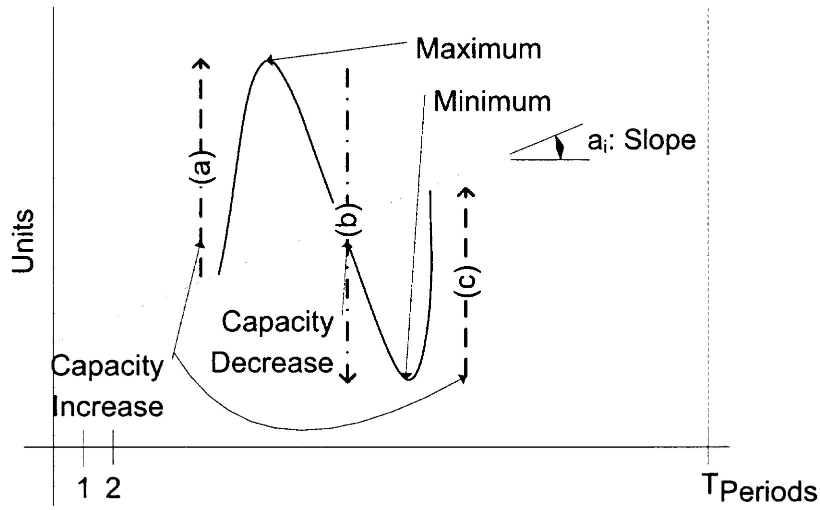



**Figure 4.2** Demand variation in a single cycle.

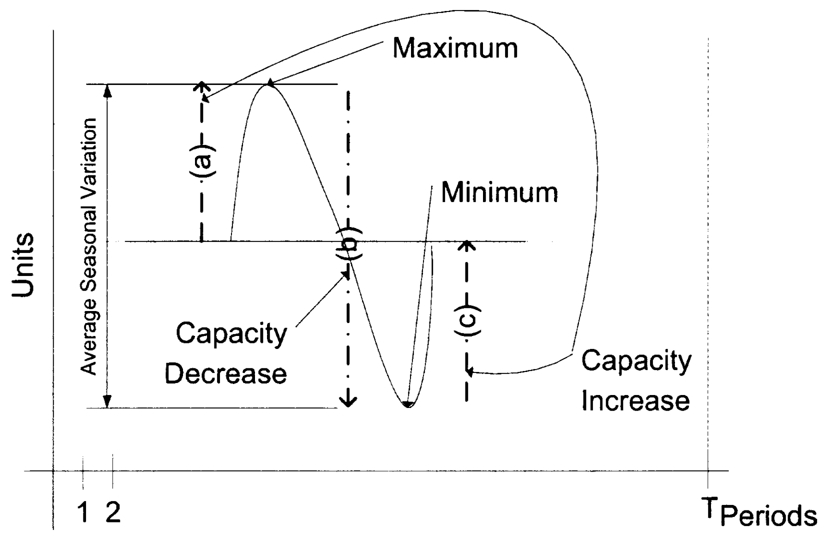



**Figure 4.3** Demand variation due to seasonality.

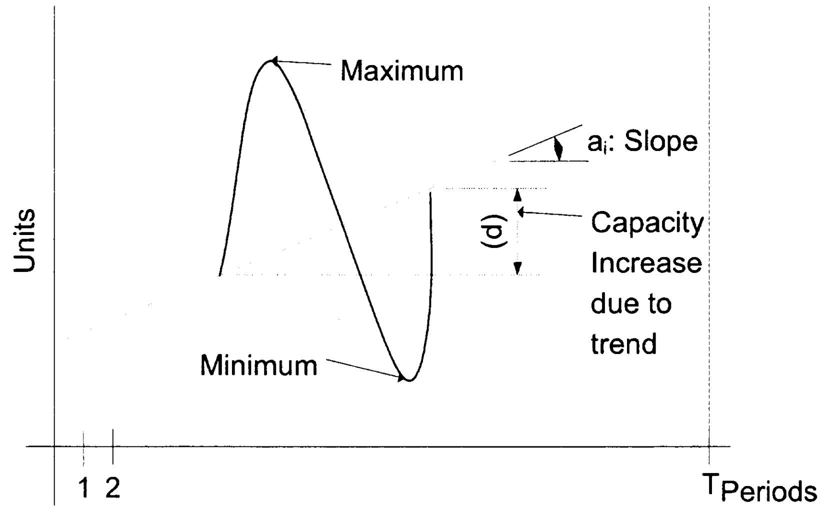
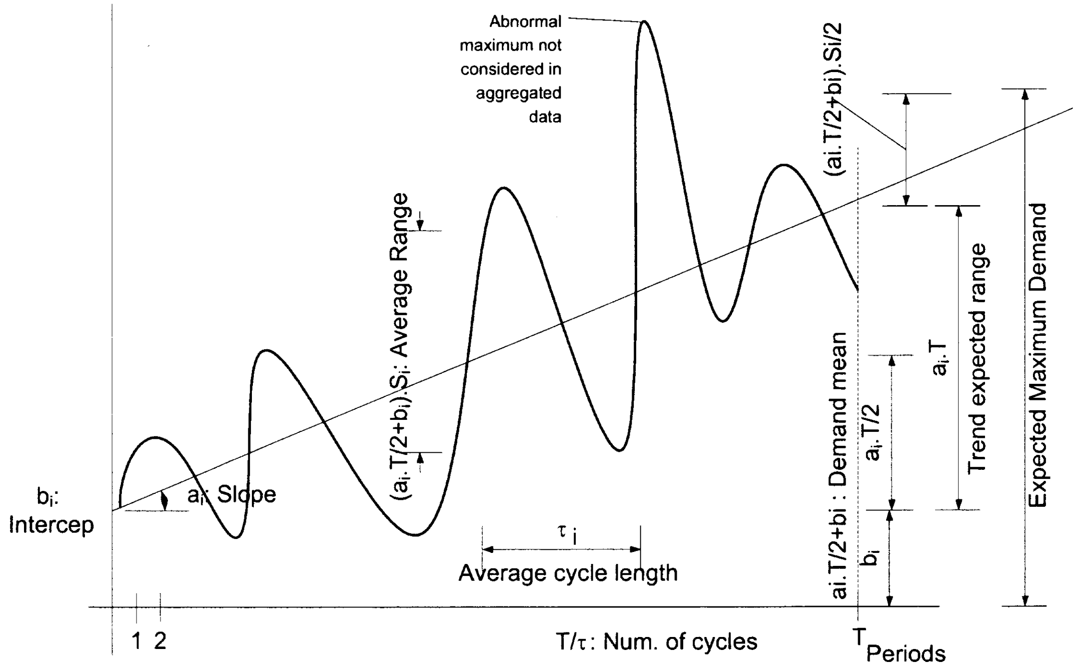



**Figure 4.4** Demand variation due to trend.

Analyzing the figures some relationships are identified:

- Demand variation per cycle is equal to the sum of demand variation due to seasonality and demand variation due to trend.
- Total hiring per cycle is equal to the sum of hiring due to seasonality and hiring due to trend.
- Hiring due to seasonality is equal to average seasonal variation.
- Hiring due to trend is equal to capacity increase due to trend.
- Total firing per cycle, firing due to seasonality, and average seasonal variation are equal.
- Total hiring in the planning horizon is equal to total hiring per cycle multiplied by the number of cycles.
- Total firing in the planning horizon is equal to total firing per cycle multiplied by the number of cycles.

This basic reasoning and the auxiliary variables derived from the demand characterization allows the development the strategic model.




$\frac{a_i \times T^2 + 2b_iT}{2}$ total number of units processed

**Figure 4.5** Auxiliary formulas from demand characterization.

Figure 4.5, illustrates the auxiliary formulas used to characterize demand and develop the model. Some are listed bellow, but the complete list is on section 4.3.1, equations (4.10) to (4.21).

| | | |
|---|---|---|
| $T/\tau_i$ | Number of seasonal cycles; | (4.1) |
| $\frac{a_iT}{2}+b_i$ | Mean demand in customers per unit time per service *i;* | (4.2) |
| $a_iT+b_i$ | Trend maximum demand expected for the planning period for service *i;* | (4.3) |
| $a_iT$ | Trend expected range of demand for service *i;* | (4.4) |
| $\left(\frac{a_iT}{2}+b_i\right)S_i$ | Average range of the fluctuation in demand attributed to seasonality; | (4.5) |

| | | |
|---|---|---|
| $a_i \times T + b_i + \left( a_i \frac{T}{2} + b_i \right) \frac{S_i}{2}$ | An aggregated value of the maximum demand expected for the planning period for service *i;* | (4.6) |
| $\frac{a_i \times T^2 + 2b_i T}{2}$ | An approximation of the total number of units processed for service *i.* | (4.7) |

## 4.2 Demand Change Parameters

Several methods could be used to forecast demand. However, the forecast will be inaccurate due to the long-term horizon. At the strategic level, the objective of the demand forecast is to quantify the expected demand variation. An accurate forecast of demand for a specific time period is not relevant at this level. The main objective is to quantify variation per seasonal cycle and growth trend. Here, a method to quantify cumulative demand variation is presented.

Once the demand for the planning horizon has been forecasted (for example by using classic time-series decomposition), it is necessary to smooth or rearrange the forecast to quantify the total increase and total decrease in demand per seasonal cycle. The following is a method for quantifying total demand variation:

- Using the forecasted demand for the strategic planning horizon, follow the succeeding steps for each seasonal cycle.
- Calculate the variation for each time period.

$$\Delta D(t)=D(t)-D(t-1). \quad (4.8)$$

Where $\Delta D(t)$ is the variation of demand for period $t$, and $D(t)$ is demand for period $t$

- Determine if the seasonal cycle starts with a positive or negative growth trend.

$$\Delta D(1)>0. \quad (4.9)$$

- Sort the variation in decreasing order if the seasonal cycle starts with a growth trend (increasing order if it starts with a negative growth trend)

- Recalculate the forecast using the rearranged differences.
- For each seasonal cycle, calculate the maximum, minimum, and range.
- For the forecasting horizon, calculate the average seasonal maximum, the average seasonal minimum, and the average seasonal range.
- For the rearranged forecast, calculate the growth intercept, slope, and average; with that information calculate the seasonal index $S_i$.

For a detailed numerical example, see the appendix (page 161).

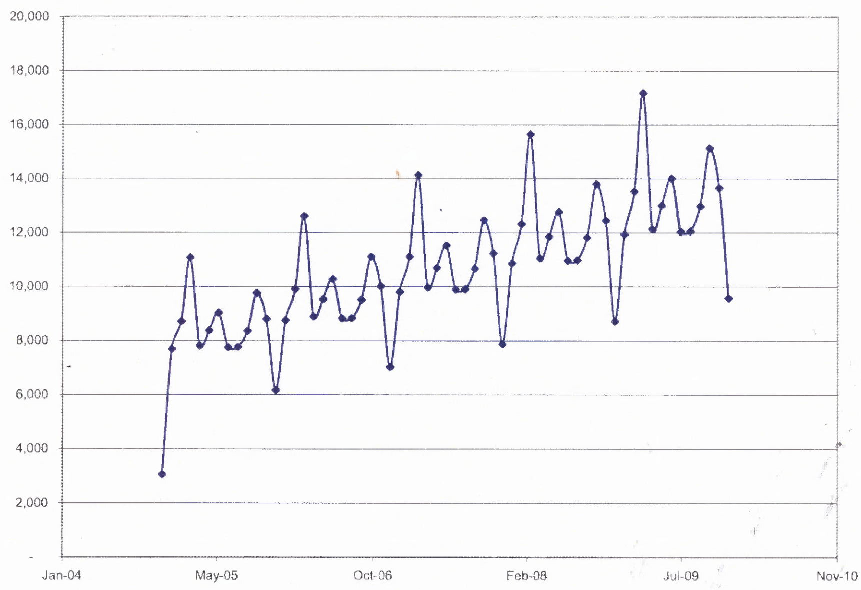



**Figure 4.6** Example of forecasted demand.

Figure 4.6 shows the forecasted demand for a service product over a five-year period. The forecasted demand presents seasonal and trend growth components. Each seasonal period (year) presents several increases and decreases in demand that affect the capacity required by the chain. The interest is in the cumulative changes in demand for the period and therefore the forecast will be smoothed. Figure 4.7 shows the result of smoothing the forecast. This information is used to determine the demand parameters required to compare the different service suppliers.

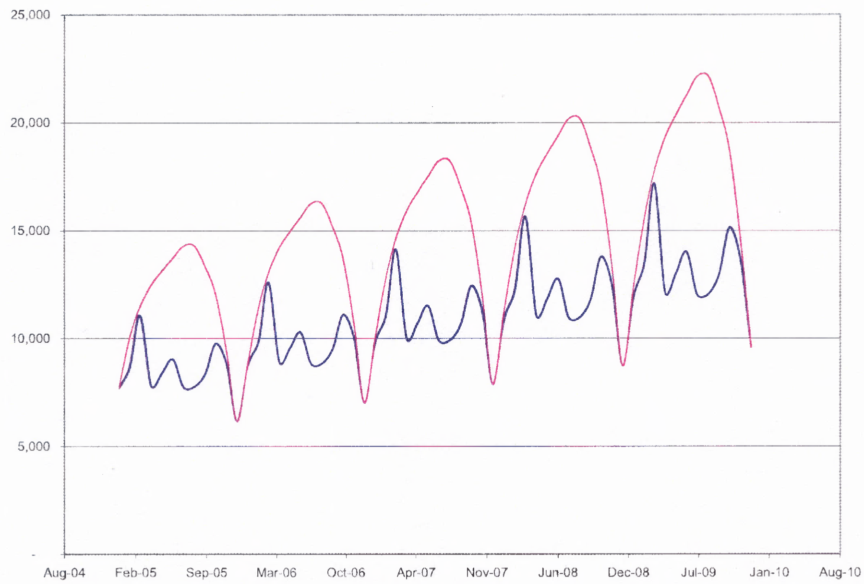



**Figure 4.7** Example of smoothed forecast.

## 4.3 The Strategic Model

The main goal of the model is to select service providers and assign tasks to them in a way that will minimize costs (initial and projected operational cost). It considers the capital expenditures associated with setting up the supply chain, hiring and firing costs, expected hiring/firing response time and its effect in backlog cost, labor costs, and expected cost due to low quality services. The model considers the entire chain—all services, all tasks, and all providers in an integrated analysis—reaching an optimal solution across the chain instead of localized optimal solutions (for an individual service or task). The model will be formulated as a multi-objective problem with weighted objectives. The problem is transformed to a single objective optimization problem.

Once the competing service providers are pre-qualified, the model selects the ones that will become part of the SSC and assigns tasks among them based on the cost parameters of each provider and the variability of demand. A service provider can be assigned several tasks based on its capabilities and the maximum capacity it can handle. If one provider offers the lowest cost across all categories, no decision is needed. The demand forecast for each service product is translated into demand for specific tasks, considering all the services that require each task.

The main decision variables are:

- Providers to be selected
- Task to be assigned

The above variables are binary and therefore the problem can be solved using a binary integer-programming model.

### 4.3.1 Notation

Recalling the parameters, variables, and auxiliary equations presented so far, the following is the notation for the model (Figure 4.8):

**Indexes:**

| | |
|---|---|
| $i = 1,\ldots, n$ | Services to be offered to the customer by the chain; |
| $j = 1,\ldots,m$ | Tasks necessary to complete each service; |
| $k= 1,\ldots,o$ | Service providers, each one capable of performing one or more tasks ; |

**Demand Characterization:**

| | |
|---|---|
| $a_i$: | Slope of demand curve for service $i$; |
| $b_i$: | Intercept of the demand curve for service $i$; trend minimum demand expected for the planning period for service $i$; |
| $T$: | Number of periods (months) in the planning horizon; |
| $S_i$: | Average range of the cyclical index; |
| $\tau_i$: | Average length of seasonal cycles; |

**Characterizations of Services and tasks:**

| | |
|---|---|
| $R_{ij}$ | Indicates if task $j$ is required for service $i$ (binary); |
| $E_i$ | Backlog cost per service. |
| $W_j$ | Base task rate (Units per server per task under "normal" conditions) ; |

**Objective Function Weight Parameters:**

| | |
|---|---|
| $\iota$ | Factor capital cost; |
| $\theta$ | Factor quality value; |
| $\eta$ | Factor hiring cost; |
| $\phi$ | Factor firing cost ; |
| $\beta$ | Factor for backlog; |
| $\chi$ | Factor for excess capacity; |
| $\lambda$ | Factor for labor cost; |

**Service Provider descriptors:**

| | |
|---|---|
| $Q_k$ | Probability of task performed with poor quality at provider $k$; |
| $U_k$ | Delay in service delivery caused by reprocessing a job in provider $k$; |
| $H_k$ | Hiring cost; |
| $F_k$ | Firing cost; |
| $D_k$ | Hiring response time, expected delay (average delay x probability of delay per unit); |
| $Z_k$ | Firing response time, expected delay (average delay x probability of delay per worker); |
| $L_k$ | Labor cost; |
| $C_k$ | Capital cost ; |
| $P_k$ | Productivity = 0.0% … 100% $P_k > 0$; |
| $G_k$ | Max capacity (# servers); |
| $V_{jk}$ | Capability of provider $k$ to perform task $j$ (binary); |

**Decision Variables:**

| | |
|---|---|
| $X_{jk}$ | Task assignment (binary); |
| $Y_k$ | Select provider (binary) . |

**Auxiliary Equations:**

| | | |
|---|---|---|
| $\dfrac{T}{\tau_i}$ | Number of seasonal cycles; | (4.10) |
| $\dfrac{a_i T}{2} + b_i$ | Mean demand in customers per unit time per service *i*; | (4.11) |
| $a_i T + b_i$ | Trend maximum demand expected for the planning period for service *i;* | (4.12) |
| $a_i T$ | Trend expected range of the demand for service *i*; | (4.13) |
| $\left(\dfrac{a_i T}{2} + b_i\right) S_i$ | Average range of the fluctuation in demand attributed to seasonality; | (4.14) |
| $\sum_{i=1}^{n} R_{ij} \times a_i T$ | Expected variation of the demand for each task attributed to growth trend; | (4.15) |
| $\sum_{i=1}^{n} R_{ij} \times \left(\dfrac{a_i \times T}{2} + b_i\right)$ | Average demand per task *j*; | (4.16) |
| $T \sum_{i=1}^{n} R_{ij} \left(\dfrac{a_i T}{2} + b_i\right) \dfrac{S_i}{\tau_i}$ | Expected variation of the demand for each task attributed to seasonality; | (4.17) |
| $T \sum_{i=1}^{n} R_{ij} \left( \mathrm{a_i} + \left(\dfrac{a_i \times T}{2} + b_i\right) \dfrac{S_i}{\tau_i} \right)$ | Aggregated value of the variation in demand per task; | (4.18) |
| $a_i \times T + b_i + \left(a_i \dfrac{T}{2} + b_i\right) \dfrac{S_i}{2}$ | Aggregated value of the maximum demand expected for the planning period for service *i*; | (4.19) |
| $\dfrac{a_i \times T^2 + 2b_i T}{2}$ | Approximation of the total number of units processed for service *i*; | (4.20) |
| $\dfrac{1}{2} \sum_{i=1}^{n} R_{ij} (a_i \times T^2 + 2b_i T)$ | Approximation of the total number of units processed for task *j*. | (4.21) |

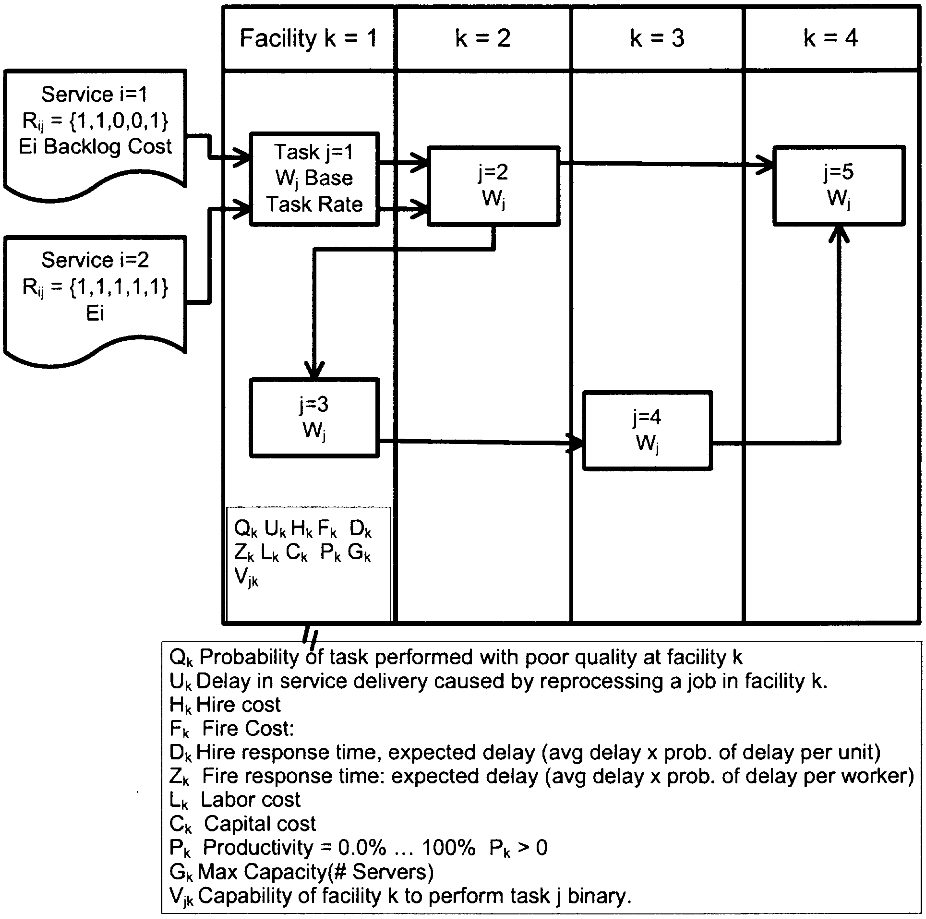



**Figure 4.8** Strategic model parameters.

### 4.3.2 The Strategic Model Objective Function

In this section, the different costs that affect the service provider selection and task assignment decisions are analyzed to build the objective function.

**Capital Cost**: The cost associated with selecting a service provider is independent of the number of tasks assigned to that provider. This cost includes the initial investment, equipment, training, and contract negotiations, and it is not the same for all service providers.

Capital Cost:

$$\iota \sum_{k=1}^{p} Y_k C_k \ . \tag{4.22}$$

Where:

$\iota$ Factor capital cost

$Y_k$ Select provider (binary)

$C_k$ Capital cost

**Hiring cost**: When hiring, service providers incur costs associated with searching for, hiring, and training new workers. These costs will be reflected as a monetary charge to the supply chain leader. When hiring and firing costs are low, the SSC is more flexible. When different tasks assigned to the same provider have negative demand correlation, there is cross compensation of demand variability within the chain. The model assumes that providers have a flexible workforce.

The hiring and firing costs are affected by several factors:

- Demand variability attributed to growth.
- Demand variability attributed to seasonality.
- Productivity - If productivity is high, the number of workers that need to be hired/fired to cope with demand variability is less.
- Number of tasks assigned to a service provider - When several tasks are assigned to a single service provider, workers move from one task to another.

To calculate the cost of hiring for each task assigned to a provider, multiply the expected increase in demand for a single task during the planning horizon, equation (4.18), by $H_k$, and $X_{jk}$, and obtain the number of servers, dividing by the base rate per task multiplied by productivity per server

$$\frac{H_k X_{jk}}{W_j P_k} T \sum_{i=1}^{n} R_{ij} \left( a_i + \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} \right). \tag{4.23}$$

Therefore, the total hiring cost for the provider is the summation of all the hiring costs per task assigned to that provider.

Hiring cost per provider:

$$\sum_{j=1}^{m} \frac{H_k X_{jk}}{W_j P_k} T \sum_{i=1}^{n} R_{ij} \left( a_i + \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} \right). \tag{4.24}$$

The total hiring cost for the Service Supply Chain is the summation of the hiring cost for all the providers:

$$\sum_{k=1}^{p} \sum_{j=1}^{m} \frac{H_k X_{jk}}{W_j P_k} T \sum_{i=1}^{n} R_{ij} \left( a_i + \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} \right). \tag{4.25}$$

Multiplying by the appropriate weight factor and rearranging terms in the equation, the hiring cost is:

$$\eta T \sum_{k=1}^{p} \frac{H_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( a_i + \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} \right). \tag{4.26}$$

**Firing cost:** When firing employees, service providers might incur several costs, including legal or punitive restrictions, costs of possible legal action, fines and taxes imposed by the government in the event that a worker is fired, and severance payments. The model considers only a positive growth trend; therefore, firing is only a result of seasonal changes:

$$\phi T \sum_{k=1}^{p} \frac{F_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i}. \tag{4.27}$$

**Hiring response time**: Variations in service delivery times affect the customer perception of quality. When there is a spike in demand, the chain reacts by increasing capacity. If the increase in capacity is not accomplished fast enough, there will be backlogs. Backlogs represent a cost to the SSC because they negatively affect customer perception of quality and may cause loss of customers. The model assumes that the response time is the same, independently of the number or servers required.

The model uses a probabilistic approach to calculate the expected delay caused by hiring response time. It requires a parameter $D_k$ that is calculated by multiplying the average delay in hiring by the probability that a service request will be delayed because of insufficient capacity. Each service provider has its own average hiring delay parameter. The probability that a service request will be delayed due to an insufficient number of servers is a function of the accuracy of the demand forecast and the responsiveness of the service provider. How to calculate expected delay due to hiring response time is outside of the scope of this dissertation.

Multiplying the total number of service requests processed for a particular task, equation (4.21), by $D_k$ gives the total number of days (units delayed by days per unit) that this task will be delayed because of hiring response time at service provider $k$.

$$D_k \sum_{i=1}^{n} R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.28}$$

Summing up for all the tasks assigned to the service provider and for all the services, and multiplying by the respective backlog cost per service product, gives:

$$\sum_{k=1}^{p} D_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} E_i R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.29}$$

Multiplying by the appropriate weight factor and rearranging terms in equation (4.29), the hiring response cost is:

$$\frac{\beta T}{2}\sum_{k=1}^{p} D_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} E_i R_{ij}\left(a_i T + 2b_i\right). \tag{4.30}$$

**Firing response time**: When a reduction in capacity is needed to respond to demand, the service providers might be limited by regulation and contractual conditions. This might cause a delay. This delay causes unused capacity because there will be more employees than needed. In this section, the cost associated with this unused capacity is quantified.

The model uses a probabilistic approach to calculate the expected firing delay per worker. It requires a parameter $Z_k$ that is calculated multiplying the average delay in firing by the probability of firing delay per worker. Each service provider has its own average firing delay parameter. The probability of firing delay per worker is a function of the accuracy of the demand forecast, the responsiveness of the service provider, regulations, and conditions of the workforce. The calculation of expected delay per worker fired $Z_k$ is outside the scope of this dissertation.

The model assumes a growing trend, so there will only be firings due to seasonality. Multiplying the expected decrease in demand for a service product in a single seasonal cycle (4.14) by the number of cycles on the planning horizon (4.10), the expected total decrease in demand for a service product due to seasonality is obtained. The expected decrease in demand for a single task during the planning horizon is the summation of the decreases in demand for all the services that require that task (equation (4.17)):

$$T\sum_{i=1}^{n} R_{ij}\left(\frac{a_i T}{2} + b_i\right)\frac{S_i}{\tau_i}. \tag{4.17}$$

The number of servers that will be fired for each task assigned to a provider is calculated multiplying (4.17) by the decision variable that assigns a task to a provider, $X_{jk}$ and dividing by the base rate per task multiplied by productivity per server.

$$\frac{X_{jk}}{W_j P_k} T \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i}. \tag{4.31}$$

The extra capacity (number of workers) is calculated by multiplying equation (4.31) by $Z_k$. Then, multiplying by labor cost $L_k$, gives the total cost of firing delays for a particular task

$$\frac{Z_k L_k X_{jk}}{W_j P_k} T \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i}. \tag{4.32}$$

The firing delay cost per service provider is obtained by summing up over all the tasks assigned to a service provider:

$$\frac{Z_k L_k}{P_k} T \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i}. \tag{4.33}$$

Doing a summation for all the service providers, multiplying by the appropriate weighting factor and rearranging terms yields the total firing response cost for the Service Supply Chain during the planning horizon:

$$\chi T \sum_{k=1}^{p} \frac{Z_k L_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i}. \tag{4.34}$$

**Labor cost**: Services with high information content require labor as the main resource to process them. The model assumes that the standard worker can process a certain number of service requests per unit time. This is called the base rate per task, $W_j$. To reflect the different skills of the labor force at different locations, this rate is adjusted at each service provider using a productivity factor $P_k$ (0% to 100%); a service provider with $P_k$=100% will perform any task assigned to it at the base rate. A lower productivity means that the service provider will process fewer service requests at each task than the base rate.

The total number of times that a particular task needs to be processed during the planning horizon is given by equation (4.21). The total labor cost per provider is obtained by dividing (4.21) by the base task rate and productivity, and summing up for all the tasks assigned to the service provider.

$$\frac{1}{2}\sum_{j=1}^{m}\frac{X_{jk}L_k}{W_jP_k}\sum_{i=1}^{n}R_{ij}\left(a_iT^2+2b_iT\right). \tag{4.35}$$

To obtain the total labor cost for the Service Supply Chain is obtained by adding the labor cost of all the providers. Multiplying by the appropriate weighting factor and rearranging terms, the total labor cost for the Service Supply Chain is expressed as:

$$\frac{\lambda T}{2}\sum_{k=1}^{p}\frac{L_k}{P_k}\sum_{j=1}^{m}\frac{X_{jk}}{W_j}\sum_{i=1}^{n}R_{ij}\left(a_iT+2b_i\right). \tag{4.36}$$

**Quality cost**: is the cost incurred by the SSC leader because the product or service did not meet the customer requirements or expectations. The model assumes that service jobs with poor quality require reprocessing, occasioning additional costs— labor, and backlog costs.

Doing a summation of the total number of times that a task needs to be processed (4.21) for all the tasks assigned to a particular service provider, yields the total number of service requests processed by a service provider:

$$\sum_{j=1}^{m}X_{jk}\sum_{i=1}^{n}R_{ij}\frac{a_iT^2+2b_iT}{2}. \tag{4.37}$$

$Q_k$ represents the probability that a task performed at provider $k$ will be of poor quality. Therefore, multiplying the total number of service requests processed by a service provider by $Q_k$, the total number of task performed at provider $k$ with poor quality is obtained:

$$Q_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.38}$$

To calculate the labor cost required for reprocessing, divide (4.38) by the base task rate and productivity, and multiply by the labor cost at the service provider. Therefore, the labor component of the low quality cost per service provider is:

$$\frac{Q_k L_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.39}$$

To calculate the backlog cost caused by reprocessing, multiply the total number of task performed at provider $k$ with poor quality by $U_k$ the delay in service delivery caused by reprocessing a job in provider $k$:

$$Q_k U_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.40}$$

Then multiply by $E_i$, the backlog cost per service $i$, so the backlog cost caused by reprocessing at a service provider is:

$$Q_k U_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} E_i R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.41}$$

Adding the two cost elements of low quality cost per service provider gives:

$$\frac{Q_k L_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \frac{a_i T^2 + 2b_i T}{2} + Q_k U_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} E_i R_{ij} \frac{a_i T^2 + 2b_i T}{2}. \tag{4.42}$$

Doing a summation for all the service providers, multiplying by the appropriate weighting factor and rearranging terms, the total low quality cost for the Service Supply Chain is as follows:

$$\frac{\theta T}{2}\sum_{k=1}^{p}\left(Q_k\left(\frac{L_k}{P_k}\sum_{j=1}^{m}\frac{X_{jk}}{W_j}\sum_{i=1}^{n}R_{ij}(a_iT+2b_i)+U_k\sum_{j=1}^{m}X_{jk}\sum_{i=1}^{n}E_iR_{ij}(a_iT+2b_i)\right)\right). \qquad (4.43)$$

### 4.3.3 Constraints

There are several constraints associated with the model:

**Capacity**: each provider has a fixed maximum capacity expressed by the number of servers (workers) it can support. This, and the number of tasks assigned to a particular provider limits the number of units it can process. In this model, total demand should be satisfied. To be considered as a candidate, a service provider should be pre-qualified by demonstrating that it has the capacity to cover the maximum demand of at least one task across all services that require that task.

For each service, the expected maximum demand during the planning horizon is given by equation (4.19). Thus, for each task, the maximum demand required is:

$$\sum_{i=1}^{n}\left(R_{ij}\left(a_iT+b_i+\left(a_i\frac{T}{2}+b_i\right)\frac{S_i}{2}\right)\right). \qquad (4.44)$$

Multiplying by the capability of provider $k$ to perform task $j$ ($V_{jk}$) and transforming the requests in units to requirements in labor by dividing by the base task rate and productivity, yields the maximum number of servers required per task at a particular provider:

$$\frac{V_{jk}}{W_j P_k}\sum_{i=1}^{n}\left(R_{ij}\left(a_i T + b_i + \left(a_i \frac{T}{2} + b_i\right)\frac{S_i}{2}\right)\right). \tag{4.45}$$

The maximum number of servers required at each provider (if all tasks that it is capable of providing are assigned to it) is obtained by doing a summation for all the tasks that a service provider is capable of offering:

$$\sum_{j=1}^{m}\frac{V_{jk}}{W_j P_k}\sum_{i=1}^{n}\left(R_{ij}\left(a_i T + b_i + \left(a_i \frac{T}{2} + b_i\right)\frac{S_i}{2}\right)\right). \tag{4.46}$$

To be considered for task assignment a provider should satisfy the following condition for all tasks that it is competing in:

$$HC_k \geq \frac{V_{jk}}{W_j P_k}\sum_{i=1}^{n}\left(R_{ij}\left(a_i T + b_i + \left(a_i \frac{T}{2} + b_i\right)\frac{S_i}{2}\right)\right)\Bigg|\forall j. \tag{4.47}$$

For the constraint, each provider should have enough capacity to cover the maximum demand of all the tasks assigned to it:

$$G_k \geq \sum_{j=1}^{m}\frac{X_{jk}}{W_j P_k}\sum_{i=1}^{n}\left(R_{ij}\left(a_i T + b_i + \left(a_i \frac{T}{2} + b_i\right)\frac{S_i}{2}\right)\right). \tag{4.48}$$

**Task assignment constraint**: Each task should be assigned to one provider and all the tasks should be assigned.

$$\sum_{j=1}^{m} X_{jk} = 1. \tag{4.49}$$

**Provider selection**: If a task is assigned to a provider then the provider is selected.

$$X_{jk} \leq Y_k. \tag{4.50}$$

**Task capability**: A task can be assigned to a service provider only if it has the capability to perform that task.

$$X_{jk} \le V_{jk} . \tag{4.51}$$

## 4.4 Integer Programming Formulation

Objective: minimize $\iota \sum_{k=1}^{p} Y_k C_k + \eta T \sum_{k=1}^{p} \frac{H_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( a_i + \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} \right) +$

$$\phi T \sum_{k=1}^{p} \frac{F_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} + \frac{\beta T}{2} \sum_{k=1}^{p} D_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} E_i R_{ij} (a_i T + 2b_i) +$$

$$\chi T \sum_{k=1}^{p} \frac{Z_k L_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} \left( \frac{a_i T}{2} + b_i \right) \frac{S_i}{\tau_i} + \frac{\lambda T}{2} \sum_{k=1}^{p} \frac{L_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} (a_i T + 2b_i) +$$

$$\frac{\theta T}{2} \sum_{k=1}^{p} \left( Q_k \left( \frac{L_k}{P_k} \sum_{j=1}^{m} \frac{X_{jk}}{W_j} \sum_{i=1}^{n} R_{ij} (a_i T + 2b_i) + U_k \sum_{j=1}^{m} X_{jk} \sum_{i=1}^{n} E_i R_{ij} (a_i T + 2b_i) \right) \right)$$

Subject to:

$$\sum_{j=1}^{m} \frac{X_{jk}}{W_j P_k} \sum_{i=1}^{n} \left( R_{ij} \left( a_i T + b_i + \left( a_i \frac{T}{2} + b_i \right) \frac{S_i}{2} \right) \right) \le G_k ,$$

$$\sum_{j=1}^{m} X_{jk} = 1 ,$$

$$Y_k - X_{jk} \ge 0 ,$$

$$V_{jk} - X_{jk} \ge 0 ,$$

$$X_{jk} = binary ,$$

$$Y_k = binary . \tag{4.52}$$

## 4.5 Computational Complexity of the Model

The two primary determinants of computational difficulty for an IP problem are (1) the number of integer variables and (2) any special structure in the problem (Hillier et al., 2001). In the model, the decision variables $X_{jk}$ and $Y_k$ are binary. According to Hillier, several papers since the mid-1980s present new algorithmic approaches to solving pure Binary Integer Programming (BIP) problems and Mixed BIP problems, including the branch-and-cut algorithm for pure BIP. Some of the techniques used are automatic problem preprocessing, generation of cutting planes, and clever branch-and-bound techniques. Commercial software packages like CPLEX incorporate these approaches.

A sample problem has been developed to test the numerical results of the model. The problem has 4 services ($n = 4$), 11 tasks ($m$=11) and 21 facilities ($o = 21$). The size of the problem is manageable with 252 binary integer variables. The facilities are:

- 1 Mortgage Broker
- 3 Low risk appraisers
- 3 High risk appraisers
- 3 Low Risk Title Companies
- 3 High Risk Title Companies
- 3 Insurers
- 5 Lender activities offices

Assuming that one each of the above mentioned facility type categories is selected, the feasible solutions tree is reduced to 1215 branches. Therefore, the problem is easily solvable with currently available hardware and software. In trial runs (Intel Pentium 4 CPU 2.53 GHz, 1 GB RAM, and LINGO 8.0) a solution was reached in 1 second (Figure 4.9).

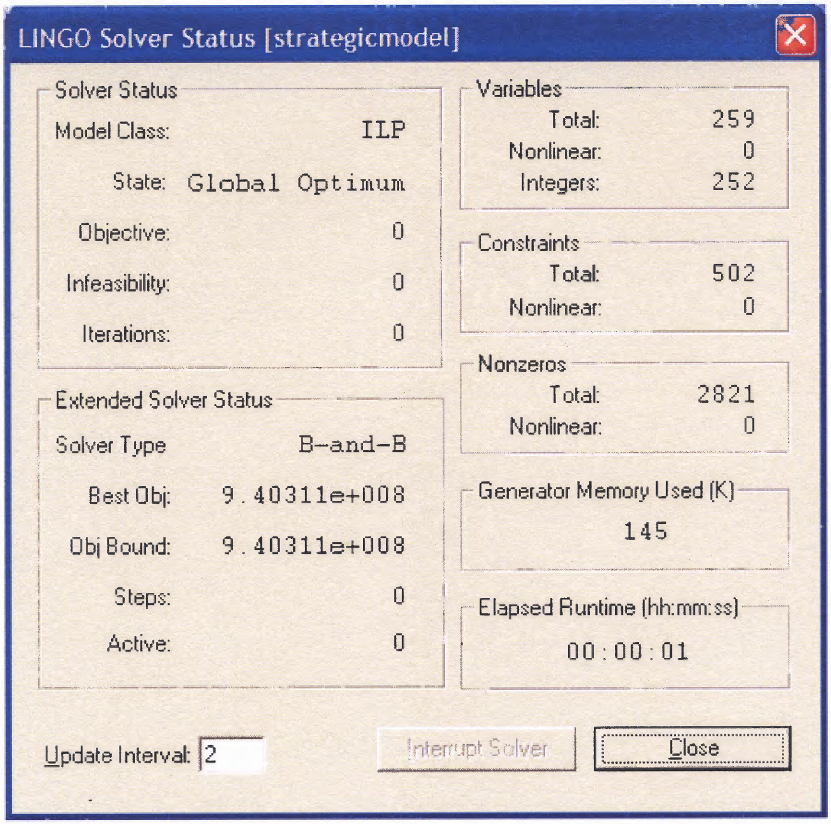



**Figure 4.9** LINGO 8.0 solver status screen for sample strategic problem.

# CHAPTER 5

# TACTICAL LEVEL: WORKFORCE LEVEL AT EACH SERVICE FACILITY

This chapter presents the results pertaining to research objective number three: to develop a tactical decision making model that will determine the workforce level required to satisfy the forecasted demand. The model considers hiring, firing, backlog and labor costs. After developing the model, its computational complexity was analyzed in order to improve it. At the tactical planning level, the number, location, and capacity constraints of the service facilities have been decided. The main decisions involve aggregate planning and the allocation of resources to different products. The time frame for this phase is 12 to 18 months.

## 5.1 Introduction

For information based services, labor costs constitute a major expense. For example, Wells Fargo & Company, a large financial services company (fifth in assets and fourth in market value) that provides banking, insurance, investments, mortgage banking, and consumer finance, reports that labor related costs—salaries, incentive compensation and employee benefits—represent 58% of its non interest expenses for the year 2006 (Table 5.1). The model presented in this chapter is derived from classical aggregated production planning models developed for the manufacturing industry. The objective is to control and reduce labor related costs to obtain competitive advantage while maintaining customer satisfaction.

**Table 5.1** Wells Fargo & Company Labor Cost 2006

| | Year ended December 31 | | |
|---|---|---|---|
| (in millions $) | 2006 | 2005 | 2004 |
| Salaries | 7,007 | 6,215 | 5,393 |
| Incentive compensation | 2,885 | 2,366 | 1,807 |
| Employee benefits | 2,035 | 1,874 | 1,724 |
| Total labor related expenses | 11,927 | 10,455 | 8,924 |
| Total non Interest expense | 20,742 | 19,018 | 17,573 |
| % of labor related expenses | 58% | 55% | 51% |

Data Source: (Wells Fargo & Company "FORM 10-K For the fiscal year ended December 31, 2005," 2006)

Hax and Candea (1984) present several aggregate production planning models for determining production, inventory, and workforce levels that can meet fluctuating demand. They include classic LP formulations for fixed and variable workforce problems. The models are developed for goods based industries with emphasis on transportation and inventory costs. Bhatnagar et al. (2003) present an LP model for contingent manpower planning based on a computer industry firm with manufacturing facilities. They consider workers with different skill sets, the use of overtime, and contingent workers with a limited set of skills to increase capacity during a new product introduction. The tactical model used here has similarities with classical aggregate production planning as well as the following important differences:

- There is no inventory between production stages. Instead, there is customer waiting.
- The backlog cost is a main component of the model.
- The production system consists of several providers managed by different companies, and the principal flow between these providers is information.

At this level, it is necessary to make decisions about the number of service units to be processed at each task, the number of servers at each provider, and adjustments to the number of servers (hiring, firing) to closely match forecasted demand. These decisions are made within the constraints imposed by the strategic level, such as, what providers are part of the chain, what is their maximum capacity, and what tasks are assigned to each provider. The model assumes that the servers at each provider are able to perform all the tasks assigned to them, and therefore can move from one task to another when changes in demand require it. The SSC adapts to changes in demand, either by adjusting the workforce levels at each provider, or by managing the backlog at each task. A balance between each strategy is reached according to the particular conditions of the problem.

The model considers the SSC as a whole, and therefore produces optimum integrated decisions. If these decisions where to be made independently at each provider, suboptimal solutions, and the known issue of the bullwhip effect could arise. The ability of making staffing decisions across the chain with a single input of demand is a main advantage of this approach.

## 5.2 Model Development

Consider a SSC with $i = 1,2,\ldots,n$ service products to be offered, and $j = 1,2,\ldots,m$ tasks required to complete all the services, where the 2 dummy tasks 1 and $m$ represent the customer request and product delivery and are assigned to a dummy facility number 1. Labor cost, hiring cost, and firing cost are zero at the dummy facility. There are $k = 1,2,\ldots, p$ different facilities, each one responsible for performing at least one task, and let $t$=1,2,...$T$ be the time index. The notation in section 5.2.1 is used for a precise description of the problem under consideration.

### 5.2.1 Notation

This section presents the notation used in the mathematical formulation.

**Indexes:**

| | |
|---|---|
| $i = 1,\ldots, n$ | Services to be offered to the customer by the chain; |
| $j = 1,\ldots m$ | Tasks necessary to complete the services—Two dummy tasks 1 and $m$ are added for modeling purposes; |
| $k= 1,\ldots,p$ | Service providers; |
| $t=1,\ldots,T$ | Time index; |

**Demand characterization:**

| | |
|---|---|
| $A_{i1t}$ | Demand arrivals per unit time per service $i$; |
| $A_{ijt}$ | Demand arrivals per unit time per task $j$ per service $i$; |

**Service and task parameters:**

| | |
|---|---|
| $E_i$ | Backlog cost per service; |
| $S_{ij\hat{j}}$ | Task precedence, for service $i$ task $j$ precedes task $\hat{j}$; |
| $B_{ijt}$ | Backlog for service $i$ at task $j$ in time $t$; |

**Service facility parameters:**

| | |
|---|---|
| $H_k$ | Hiring cost; |
| $F_k$ | Firing cost; |
| $L_k$ | Labor cost; |
| $Pj$ | Service rate per server; |
| $G_k$ | Maximum capacity (# servers); |
| $D_k$ | Minimum capacity (# servers); |
| $V_{jk}$ | Task assignment. (Binary); |

**Decision variables:**

| | |
|---|---|
| $X_{kt}$ | Number of servers at facility $k$ in period $t$ (integer); |
| $Y_{ijt}$ | Completion rate, number of jobs processed for task $j$ in period $t$ corresponding to service $i$; |
| $O_{kt}$ | Number of servers hired at facility $k$ in period $t$; |
| $U_{kt}$ | Number of servers fired at facility $k$ in period $t$. |

### 5.2.2 Objective Function and Associated Costs

There are several costs across the Service Supply Chain that affect the tactical decision making process.

**Hiring and firing costs:** The nature of these costs was discussed in the previous chapter. The hiring cost per facility is the multiplication of the hiring cost per employee by the number of hiring events in the planning horizon:

$$H_k \times \sum_{t=1}^{T} O_{kt} \ . \tag{5.1}$$

The total hiring cost for the Service Supply Chain is the summation of (5.1) over all the facilities:

$$\sum_{k=1}^{p} H_k \times \sum_{t=1}^{T} O_{kt} \ . \tag{5.2}$$

Similarly, for the firing cost:

$$\sum_{k=1}^{p} F_k \times \sum_{t=1}^{T} U_{kt} \ . \tag{5.3}$$

**Backlog:** The total backlog cost per service product is the multiplication of the backlog cost by the total number of service jobs that were delayed per unit time for that particular product. The total backlog cost across the chain is:

$$\sum_{i} E_i \sum_{j} \sum_{t} B_{i,j,t} \ . \tag{5.4}$$

**Labor cost:** The labor cost is calculated by multiplying the labor cost per facility by the number of workers per unit time.

$$\sum_{k} L_k \sum_{t} X_{k,t} \ . \tag{5.5}$$

**Objective function:** Therefore, the objective is to minimize the total cost across the Service Supply Chain:

$$\sum_k H_k \sum_t O_{kt} + \sum_k F_k \sum_t U_{kt} + \sum_i E_i \sum_j \sum_t B_{ijt} + \sum_k L_k \sum_t X_{kt} . \quad (5.6)$$

### 5.2.3 Constraints:

There are several constraints associated with the model.

**Production balance:** For each task, there is a relationship between arrivals at time $t$, backlog at the end of $t$-1, units completed at $t$ and backlog at the end of $t$.

$$B_{ijt} - A_{ijt} - B_{ijt-1} + Y_{ijt} = 0 \forall t > 1 . \quad (5.7)$$

$$B_{ijt} - A_{ijt} + Y_{ijt} = 0 \mid t = 1 . \quad (5.8)$$

In addition, the values of the backlog at the last period in the planning horizon should be specified.

$$B_{ijt} = 0 \mid t = T . \quad (5.9)$$

**Routing:** Each service may need different tasks in different sequences. For modeling purposes, a dummy facility is added with dummy task 1 and dummy task $m$ assigned to it. These represent the customer requesting a service product and the delivery of the product. To insure the proper routing of services, the following constraint is added:

$$A_{i\hat{j}t} - \sum_{\hat{j}} \sum_j Y_{ijt-1} \times S_{ij\hat{j}} = 0 \forall \hat{j} > 1 \wedge t > 1 . \quad (5.10)$$

**Capacity:** The number of service jobs processed at service facility $k$ at time $t$ for all the tasks assigned to it should be less than or equal to its capacity—given by the number of servers at $k$ adjusted for productivity. Therefore:

$$X_{kt} - \sum_i \sum_j \frac{Y_{ijt} \times V_{jk}}{P_j} \geq 0 \forall k . \tag{5.11}$$

In addition, capacity has to be between the levels imposed by technological or contractual constraints:

$$X_{kt} \leq G_k . \tag{5.12}$$

$$X_{kt} \geq D_k . \tag{5.13}$$

**Workforce balance:** In each period, a number of servers are hired or fired at each facility. The workforce balance constraint is:

$$X_{kt} - X_{kt-1} - O_{kt-1} + U_{kt-1} = 0 \forall t > 1 . \tag{5.14}$$

**All orders completion:** All arrivals should be completed for all service products:

$$\sum_t A_{i1t} - \sum_t Y_{imt} = 0 . \tag{5.15}$$

**Initial and ending conditions:** To reduce the time required to solve the problem and maintain the integrity of the solution, some elements of $A_{ijt}$, $B_{ijt}$ and $Y_{ijt}$ are specified to be equal to zero depending on the conditions of the problem. Three matrices $AI_{ijt}$, $BI_{ijt}$ and $YI_{ijt}$ with binary elements are used. When the element is equal to one, the element with the same index on the corresponding matrix is equal to zero.

$AI_{ijt}$ Binary parameter that indicates that $A_{ijt}$=0 if $AI_{ijt}$=1

$BI_{ijt}$ Binary parameter that indicates that $B_{ijt}$=0 if $BI_{ijt}$=1

$YI_{ijt}$ Binary parameter that indicates that $Y_{ijt}$=0 if $YI_{ijt}$=1

$$A_{ijt} = 0 \forall AI_{ijt} = 1 . \tag{5.16}$$

$$B_{ijt} = 0 \forall BI_{ijt} = 1 . \tag{5.17}$$

$$Y_{ijt} = 0 \forall YI_{ijt} = 1 . \tag{5.18}$$

## 5.3 Mathematical Formulation

Minimize:

$$\sum_k H_k \sum_t O_{kt} + \sum_k F_k \sum_t U_{kt} + \sum_i E_i \sum_j \sum_t B_{ijt} + \sum_k L_k \sum_t X_{kt}$$

s.t:

$$B_{ijt} - A_{ijt} - B_{ijt-1} + Y_{ijt} = 0 \forall t > 1,$$

$$B_{ijt} - A_{ijt} + Y_{ijt} = 0 \mid t = 1 \ ,$$

$$A_{i\hat{j}t} - \sum_{\hat{j}} \sum_j Y_{ijt-1} \times S_{ij\hat{j}} = 0 \forall \hat{j} > 1 \wedge t > 1 \ ,$$

$$X_{kt} - \sum_i \sum_j \frac{Y_{ijt} \times V_{jk}}{P_j} \geq 0 \forall k \ ,$$

$$X_{kt} \leq G_k ,$$

$$X_{kt} \geq D_k ,$$

$$X_{kt} - X_{kt-1} - O_{kt-1} + U_{kt-1} = 0 \forall t > 1,$$

$$\sum_t A_{i1t} - \sum_t Y_{imt} = 0,$$

$$B_{ijt} = 0 \mid t = T \ ,$$

$$A_{ijt} = 0 \forall AI_{ijt} = 1 \ ,$$

$$B_{ijt} = 0 \forall BI_{ijt} = 1 \ ,$$

$$Y_{ijt} = 0 \forall YI_{ijt} = 1 \ ,$$

$X_{kt}$: integer,

All variables $\geq 0$. (5.19)

This formulation has the following dimensions:

| | |
|---|---|
| $nmT$ | number of production balance equality constraints; |
| $3nm$ | initial and ending backlog condition constraints (aprox.); |
| $nm(T\text{-}1)$ | routing constraints; |
| $pT$ | capacity constraints; |
| $2p$ | capacity constraints (contractual); |
| $pT$ | workforce balance constraints; |
| 1 | all order completion constraint; |
| $pT$ | integer decision variables; |
| $nmT+2pT$ | continuous variables; |
| $nmT+3pT$ | variables. |

## 5.4 Improving the Model to Reduce Computational Complexity

The computational complexity of the model as formulated is large, and the first runs with a sample problem ran for several hours without reaching a solution. Several techniques were used to reduce the running time of the model.

The problem used for testing the model has 4 services, 13 tasks, 8 facilities, and 30 time periods. LINGO reports 4,020 variables, with 240 integer variables and 3,981 constraints (Figure 5.1).

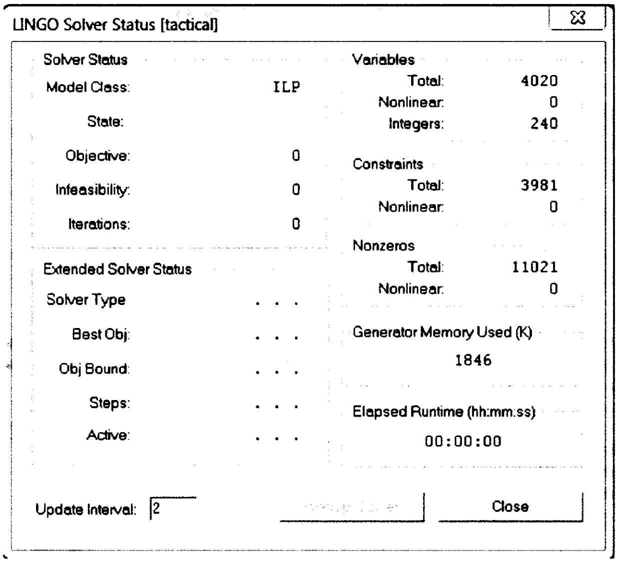



**Figure 5.1** Sample information screen for the tactical model before improvement.

**Reduce the number of variables**: To reduce the number of variables the number of servers at facility 1 is set to the maximum. The following constraint is added to the formulation.

$$X_{1t} = G_1 . \tag{5.20}$$

A set NR containing the pairs $(i,j)$ indicate that service $i$ does not require task $j$. Therefore $A_{ijt}$, $B_{ijt}$ and $Y_{ijt}$ are zero for all $(i,j) \in$ NR in all time periods.

$$A_{ijt} = 0 \forall (i,j) \in NR \wedge \forall t . \tag{5.21}$$

$$B_{ijt} = 0 \forall (i,j) \in NR \wedge \forall t . \tag{5.22}$$

$$Y_{ijt} = 0 \forall (i,j) \in NR \wedge \forall t . \tag{5.23}$$

**Sparsity**: The routing constraint uses a transition matrix S because the model assumes that service jobs could go from any task to any other. This is unrealistic in a large problem, and a smaller number of routes is necessary. A set R containing the elements $(i,j_1,j_2)$ indicating that a job of service $i$ goes from task $j_1$ to $j_2$ is used to take advantage of sparsity. The routing constraint is changed to:

$$A_{ij_2t} = Y_{ij_1t-1} \forall (i, j_1, j_2) \in R \wedge t > 1 . \tag{5.24}$$

**Relative optimality**: This is a parameter ($r$) for the integer-programming solver in LINGO. It tells the solver to only look for integer solutions with objective values at least 100*$r$% better than the best integer solution found so far, where $r$ is a number between 0 and 1. This guarantees a solution within 100*$r$% of the true optimum, and can considerably reduce the solution time. In LINGO, the default for the relative optimality tolerance is 5e-8. It was set to different values from 0.01 to 0.001.

**Reduce the solution space** (Heuristics): The final integer solution is expected to be close to the optimal linear solution of the problem. Therefore, to reduce the solution space, the problem is solved in two steps. In the first step, the integer constraint for $X_{kt}$ is relaxed and the problem is solved as a linear programming problem. The solution $X_{kt}$ is fed into the integer model as $X0_{kt}$, and used for bounding the integer programming problem. In the second step, a parameter *BOUND* is defined, and only integer solutions in the range $X0_{kt}*(1\text{-}BOUND) \leq X_{kt} \leq X0_{kt}*(1+BOUND)$ are allowed.

**Initial and ending workforce**: The parameters $XI_k$ and $XTMAX_k$ indicate the initial and final workforce level at facility $k$.

$$X_{k1} = XI_k . \tag{5.25}$$

$$X_{kT} = XTMAX_k . \tag{5.26}$$

## 5.5 Improved Mathematical Formulation

The mathematical formulation of the tactical model changes after using all the improvements. First, it is necessary to solve the linear model, and then to feed the results of the linear model to the mixed integer model.

Linear model:

Minimize: $\sum_k H_k \sum_t O_{kt} + \sum_k F_k \sum_t U_{kt} + \sum_i E_i \sum_j \sum_t B_{ijt} + \sum_k L_k \sum_t X_{kt}$

s.t:

$$
\begin{aligned}
& B_{ijt} - A_{ijt} - B_{ijt-1} + Y_{ijt} = 0 \forall t > 1, \\
& B_{ijt} - A_{ijt} + Y_{ijt} = 0 \mid t = 1, \\
& A_{ij_2t} = Y_{ij_1t-1} \forall (i, j_1, j_2) \in R \wedge t > 1, \\
& X_{kt} - \sum_i \sum_j \frac{Y_{ijt} \times V_{jk}}{P_j} \geq 0 \forall k, \\
& X_{kt} \leq G_k, \\
& X_{kt} \geq D_k, \\
& X_{kt} - X_{kt-1} - O_{kt-1} + U_{kt-1} = 0 \forall t > 1, \\
& \sum_t A_{i1t} - \sum_t Y_{imt} = 0, \\
& B_{ijt} = 0 \mid t = T, \\
& A_{ijt} = 0 \forall AI_{ijt} = 1, \\
& B_{ijt} = 0 \forall BI_{ijt} = 1, \\
& Y_{ijt} = 0 \forall YI_{ijt} = 1, \\
& X_{1t} = G_1, \\
& A_{ijt} = 0 \forall (i, j) \in NR \wedge \forall t, \\
& B_{ijt} = 0 \forall (i, j) \in NR \wedge \forall t, \\
& Y_{ijt} = 0 \forall (i, j) \in NR \wedge \forall t, \\
& X_{k1} = XI_k, \\
& X_{kT} = XTMAX_k, \\
& \text{All variables} \geq 0. \qquad (5.27)
\end{aligned}
$$

The results from the linear model ($X_{k,t}$) are fed into the mixed integer model as $XO_{kt}$ and the mixed integer formulation is:

Minimize: $$\sum_k H_k \sum_t O_{k,t} + \sum_k F_k \sum_t U_{k,t} + \sum_i E_i \sum_j \sum_t B_{i,j,t} + \sum_k L_k \sum_t X_{k,t}$$

s.t:

$$B_{ijt} - A_{ijt} - B_{ijt-1} + Y_{ijt} = 0 \forall t > 1,$$
$$B_{ijt} - A_{ijt} + Y_{ijt} = 0 \mid t = 1,$$
$$A_{ij_2t} = Y_{ij_1t-1} \forall (i, j_1, j_2) \in R \wedge t > 1,$$
$$X_{kt} - \sum_i \sum_j \frac{Y_{ijt} \times V_{jk}}{P_j} \geq 0 \forall k,$$
$$X_{kt} \leq G_k,$$
$$X_{kt} \geq D_k,$$
$$X_{kt} - X_{kt-1} - O_{kt-1} + U_{kt-1} = 0 \forall t > 1,$$
$$\sum_t A_{i1t} - \sum_t Y_{imt} = 0,$$
$$B_{ijt} = 0 \mid t = T,$$
$$A_{ijt} = 0 \forall AI_{ijt} = 1,$$
$$B_{ijt} = 0 \forall BI_{ijt} = 1,$$
$$Y_{ijt} = 0 \forall YI_{ijt} = 1,$$
$$X_{1t} = G_1,$$
$$A_{ijt} = 0 \forall (i, j) \in NR \wedge \forall t,$$
$$B_{ijt} = 0 \forall (i, j) \in NR \wedge \forall t,$$
$$Y_{ijt} = 0 \forall (i, j) \in NR \wedge \forall t,$$
$$X_{k1} = XI_k,$$
$$X_{kT} = XTMAX_k,$$
$$X_{kt} \geq X0_{kt}(1 - BOUND),$$
$$X_{kt} \leq X0_{kt}(1 + BOUND),$$

$X_{kt}$: integer,

All variables $\geq 0$. (5.28)

Solving the linear model with the sample data takes LINGO less than a second and 2,652 iterations, as shown in Figure 5.2. After implementing the changes, using a relative optimality of 0.001 and a two steps approach with BOUND = 5%, the total number of variables that LINGO reports for the MIP was reduced from 4020 variables to 2,720 , with 210 integer variables (down from 240). The number of constraints increased from 3,981 to 4,045, as shown on Figure 5.3. A solution was reached in 100 seconds and 208,432 iterations. With the original version, a solution could not be reached even after several hours. After improving the model formulation—using heuristics and relative optimality—the tactical model is computationally feasible.

The sample problem was also solved using ILOG Development Studio 5.1 (CPLEX 10.1.1) under Windows Vista Home Premium, with an Intel Core 2 6400 CPU running at 2.13 GHz. The first step (linear) reached a solution in less than a second and 639 iterations. The second step (MIP) reached a solution in less than a second with 802 iterations. The changes made to the tactical model formulation greatly improve the solution time and allows running the numerical experiments with software and hardware available in the market today.

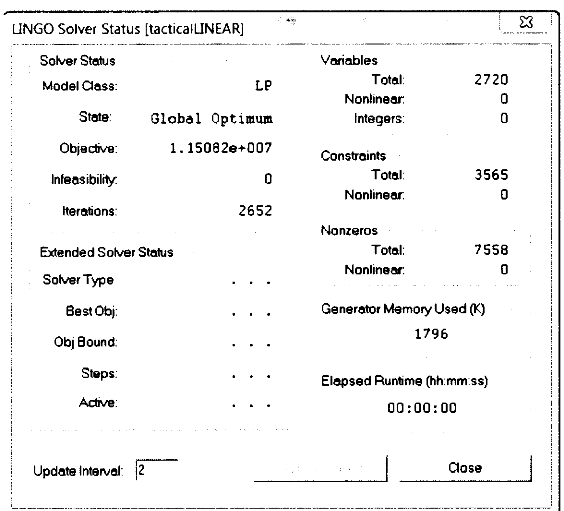



**Figure 5.2** Information screen for the first step in solving the tactical model (linear).

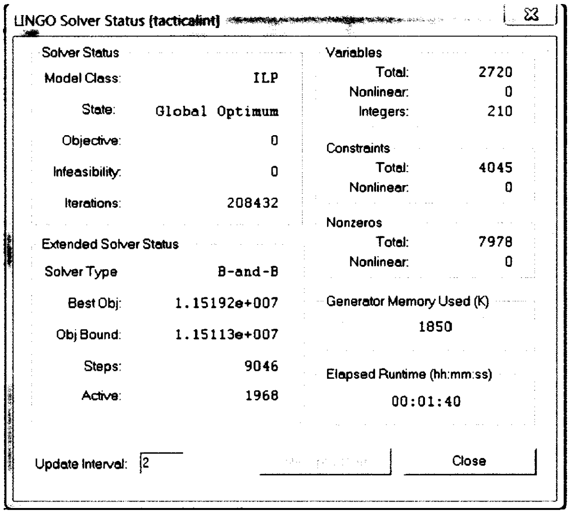



**Figure 5.3** Sample information screen for the tactical model after improvement.

# CHAPTER 6

# NUMERICAL EXPERIMENTS WITH THE STRATEGIC MODEL

This chapter presents the numerical experiments performed to achieve research objective number 4, to analyze the strategic and tactical models and several case studies to assess the validity and utility of the models. Several case studies were designed and experiments performed. This chapter presents the results of the numerical experiments with the strategic model. Chapter 7 presents the results of the numerical experiments with the tactical model. There are three main objectives for the numerical experiments:

- To determine the computational feasibility of the models, verifying that the models can be solved using available software and hardware.
- To compare the solutions provided by the models with alternative solutions provided by using heuristics.
- To evaluate how good the solutions provided by the models are when the demand behavior changes drastically from the forecast.

## 6.1 Problem Setting

This section presents an example problem to illustrate the strategic model. At the strategic level, the problem consists of selecting service facilities to provide four service products. Each service product requires the completion of up to eight tasks among 20 tasks performed by the Service Supply Chain. The different service products share at least one task with other products (Figure 6.1). Each service product starts with a request from the customer and ends with delivery to the customer. Table 6.1 presents the tasks required for each service product. There will be 24 facilities competing to provide the tasks.

The sample demand is derived from the Mortgage Applications Indexes (unadjusted) from January 2000 to December 2004 published by the Mortgage Bankers Association of America (MBA) in Mortgage Banking Magazine. Fours indexes were selected (Purchase, Refinance, FRM, ARM) and assigned to each of the service products.

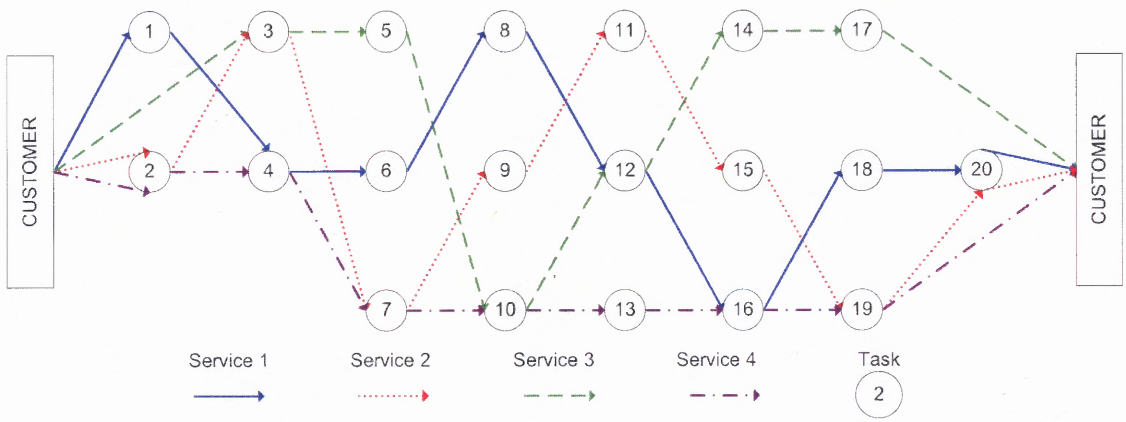



**Figure 6.1** Design of service products.

**Table 6.1** Tasks Required for Each Service Product

| | Tasks Required | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Service 1 | 1 | 4 | 6 | 8 | 12 | 16 | 18 | 20 |
| Service 2 | 2 | 3 | 7 | 9 | 11 | 15 | 19 | 20 |
| Service 3 | 3 | 5 | 10 | 12 | 14 | 17 | | |
| Service 4 | 2 | 4 | 7 | 10 | 13 | 16 | 19 | |

Demand change parameters are determined based on demand forecast and following the smoothing method described in section 4.2. They are presented in Table 6.2. The parameters are:

$a_i$: Slope of demand curve for service $i$;
$b_i$: Intercept of demand curve for service $i$. Trend minimum demand expected for the planning period for service $i$;
$T$: Number of periods (months) in the planning horizon;
$S_i$: Average range of the cyclical index;
$\tau_i$: Average length of seasonal cycles.

**Table 6.2** Numerical Example, Demand Parameters

| | | | Service Product | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| Slope | Request/ Period | $a_i$ | 25.178 | 125.518 | 82.110 | 47.036 |
| Intercept | Request | $b_i$ | 4321.2 | 10872.4 | 10557.0 | 3340.0 |
| Avg. Range of Cyclical Variation | | $S_i$ | 0.4821 | 0.7073 | 0.5891 | 0.4662 |
| Avg. Length of Cycles | Periods | $t_i$ | 12 | 12 | 12 | 12 |

Backlog costs ($/unit time) were selected randomly in average from 100 to 800 and in multiples of 10. Table 6.3 presents the backlog costs per service.

**Table 6.3** Backlog Cost per Service

| | | | Service Product | | | |
|---|---|---|---|---|---|---|
| Service | Units | | 1 | 2 | 3 | 4 |
| Backlog Cost | $/unit time | $E_i$ | 700 | 280 | 560 | 220 |

The base task rate ($W_j$) was determined by assigning to each task a uniform random number of minutes to complete (from 30 to 240). Each unit time has 9600 available minutes. The rest of the parameters were selected as geometric progressions to ensure opposing coefficients, with an added random noise of 5%. Figure 6.2 presents the service facilities descriptor normalized from 0 to 1, where 1 is the maximum value for each descriptor. The maximum capacity of all competing providers was assigned as 2500 for this first experiment. All the weighting factors (factor capital cost, factor quality value, factor hiring cost, factor firing cost, factor for backlog, factor for excess capacity, factor for labor cost) that are used to express managerial interest in a particular cost component were set to 1 in order to give them all the same importance. The task capability matrix ($V_{jk}$) was assigned with all the facilities competing for five tasks, and each task having six competing facilities.

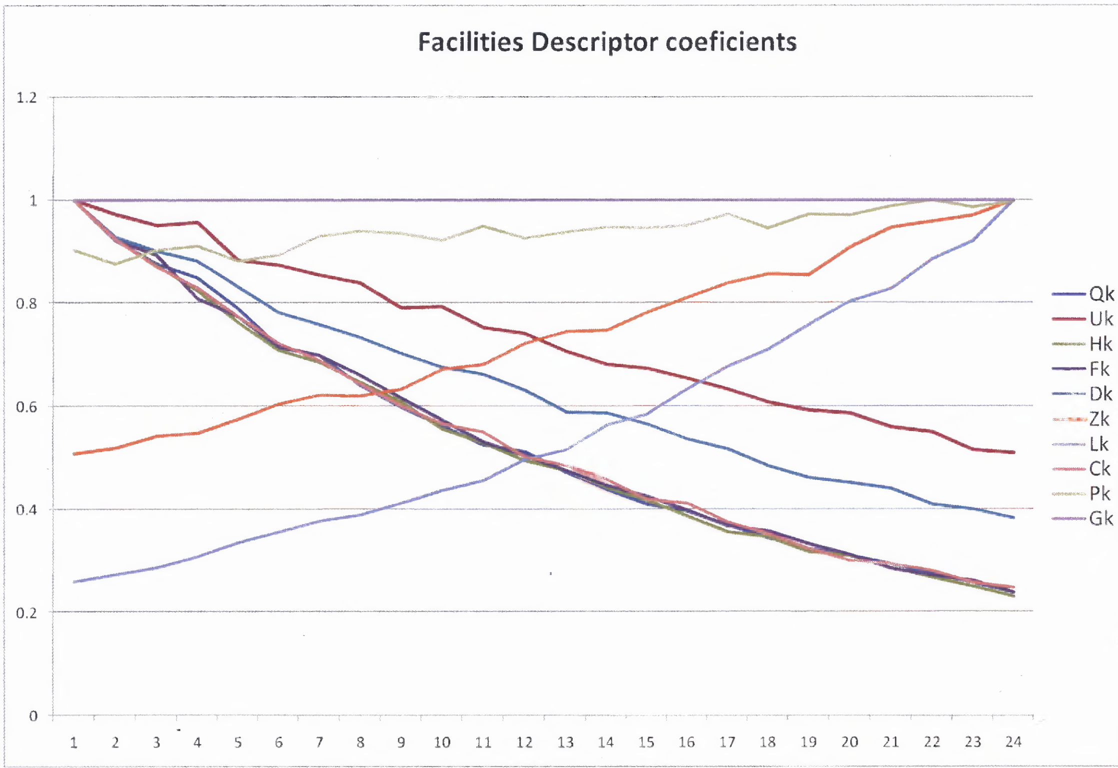



**Figure 6.2** The facilities descriptors for the numerical example are in opposition.

**Table 6.4** Task Capability

| | | Facilities | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Vjk | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Tasks | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | 5 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 6 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 7 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| | 8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | 9 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 10 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 11 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| | 12 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | 13 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 14 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 15 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| | 16 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | 17 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 18 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 19 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| | 20 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

## 6.2 Solution

This sample problem was solved using ILOG Development Studio 5.1 (CPLEX 10.1.1) under Windows Vista Home Premium, with an Intel Core 2 6400 CPU running at 2.13 GHz. A solution was reached in 6.5 seconds with the objective function having a value of $ 101,847,617. Table 6.5 shows the decision variables and cost components, while Figure 6.3 and Table 6.6 show the weight of each cost component in the solution.

In this particular problem, when a service facility is selected, all the tasks that it is capable of performing are assigned to it. The explanation for this is that the increased capital cost offsets any benefits derived from assigning a lesser number of tasks to a facility. Other examples behave differently.

**Table 6.5** Solution, Decision Variables, and Cost Components

| f | 1.0 | Facility | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Xjk | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | 1 | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| | 2 | | | | | | | | | | | | | | 1 | | | | | | | | | | |
| | 3 | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| | 5 | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| | 6 | | | | | | | | | | | | | | 1 | | | | | | | | | | |
| | 7 | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | 8 | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| | 9 | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| Tasks | 10 | | | | | | | | | | | | | | 1 | | | | | | | | | | |
| | 11 | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | 12 | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| | 13 | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| | 14 | | | | | | | | | | | | | | 1 | | | | | | | | | | |
| | 15 | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | 16 | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| | 17 | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| | 18 | | | | | | | | | | | | | | 1 | | | | | | | | | | |
| | 19 | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| | 20 | | | | | | | | | | | | | | | | 1 | | | | | | | | |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yk | | | | | | | | | | | 1 | | | 1 | | 1 | 1 | | | | | | | |

Table 6.6 Weight of Each Cost Component in the Solution

| Cost | Amount | % |
|---|---|---|
| Capital | 10,692,557 | 10% |
| Hiring | 12,373,493 | 12% |
| Firing | 10,250,049 | 10% |
| Backlog | 15,223,721 | 15% |
| Excess Capacity | 4,094,231 | 4% |
| Labor | 45,215,951 | 44% |
| Quality | 3,997,615 | 4% |
| OBJECTIVE | 101,847,617 | |

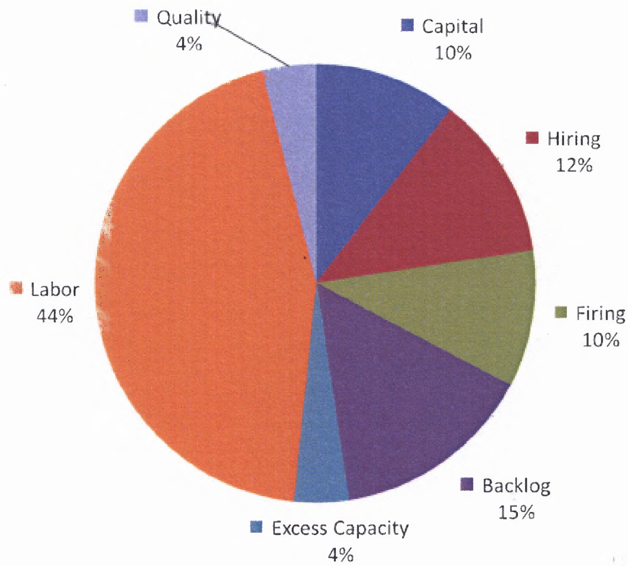



**Figure 6.3** Weight of cost components in the solution.

## 6.3 Experiment 1: Varying Hiring and Firing Cost

The experiment was designed to show how the model reacts to variations in the hiring and firing cost. A factor $f$ was used to multiply the hiring and firing cost of all the facilities ($H_k$ and $F_k$). It was changed from 0 to 2 in intervals of .5—$f$=1 is the original problem. The different results were registered and analyzed. Table 6.7 and Figure 6.4 present the effect of the experiment on the objective function and each of the cost components for the different solutions.

**Table 6.7** Cost Components for Different Solutions in Experiment 1

| Factor | 0 | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Capital | $ 14,190,098 | $ 12,524,815 | $ 10,692,557 | $ 9,271,822 | $ 7,131,694 |
| Hiring | $ - | $ 7,299,284 | $ 12,373,493 | $ 15,958,218 | $ 16,056,315 |
| Firing | $ - | $ 6,050,369 | $ 10,250,049 | $ 13,407,097 | $ 13,433,484 |
| Backlog | $ 18,300,300 | $ 16,884,702 | $ 15,223,721 | $ 13,877,629 | $ 11,603,211 |
| Excess Capacity | $ 2,685,298 | $ 3,222,829 | $ 4,094,231 | $ 5,024,671 | $ 6,842,295 |
| Labor | $ 34,152,151 | $ 38,491,071 | $ 45,215,951 | $ 51,467,165 | $ 62,996,510 |
| Quality | $ 6,166,953 | $ 5,039,705 | $ 3,997,615 | $ 3,390,056 | $ 2,544,779 |
| OBJECTIVE | $ 75,494,800 | $ 89,512,775 | $ 101,847,617 | $ 112,396,657 | $ 120,608,288 |

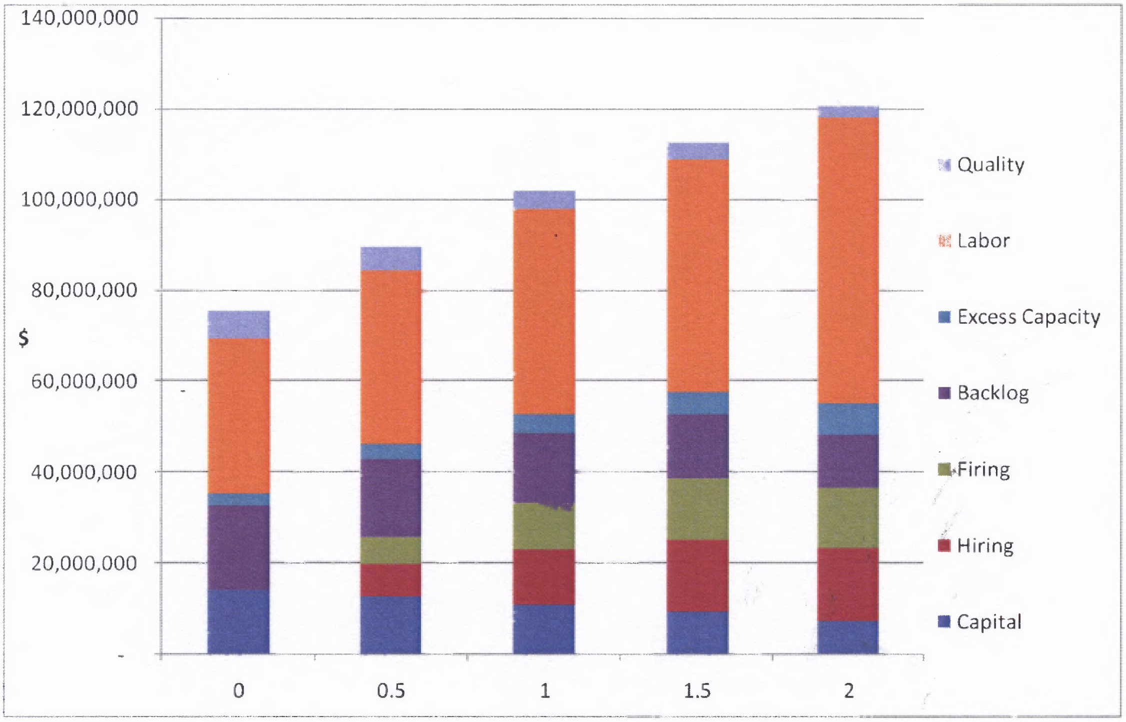
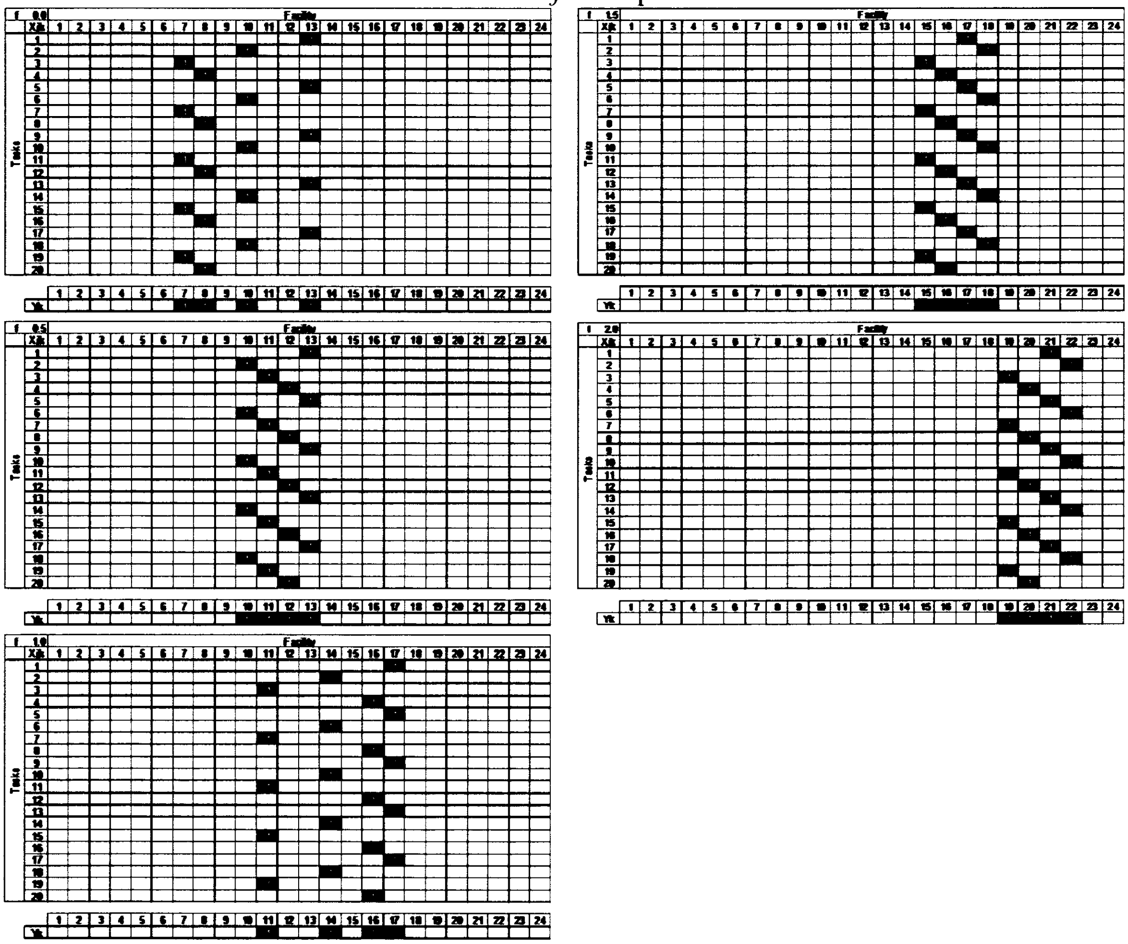



**Figure 6.4** Contribution of different cost component in experiment 1.

Table 6.8 presents the solutions for different values of *f*, including facilities selected to perform each task and the facilities that will be part of the Service Supply Chain at different levels of hiring and firing cost.

**Table 6.8** Solutions for Different Values of *f* in Experiment 1



In this experiment, no facility is dominant for any task—a single task is not assigned to a particular facility in more than two solutions and a single facility is not selected in more than two solutions. Facilities with lower labor cost are selected for lower values of *f* and facilities with higher labor cost are selected for higher ones. The opposite is true for the capital cost.

As Figure 6.5 shows, the labor cost component varies between 43% and 52% of the total objective function. The increase in hiring cost, firing cost, and excess capacity cost is balanced with reductions in the backlog cost, capital, and quality cost. This result is interesting considering that as the hiring and firing cost increases, the model selects service facilities with higher labor costs. To achieve the minimum value of the objective function, the model compensates for changes in $H_k$ and $F_k$ by changing the decision variables $X_{jk}$, so that different cost elements change at different rates and in different directions, as shown in Figure 6.6.

Solutions were contrasted to measure the impact of applying the solution obtained when $f$=0 with the conditions of $f$ =2. It was found that the objective function value increased by 15% (Table 6.9)

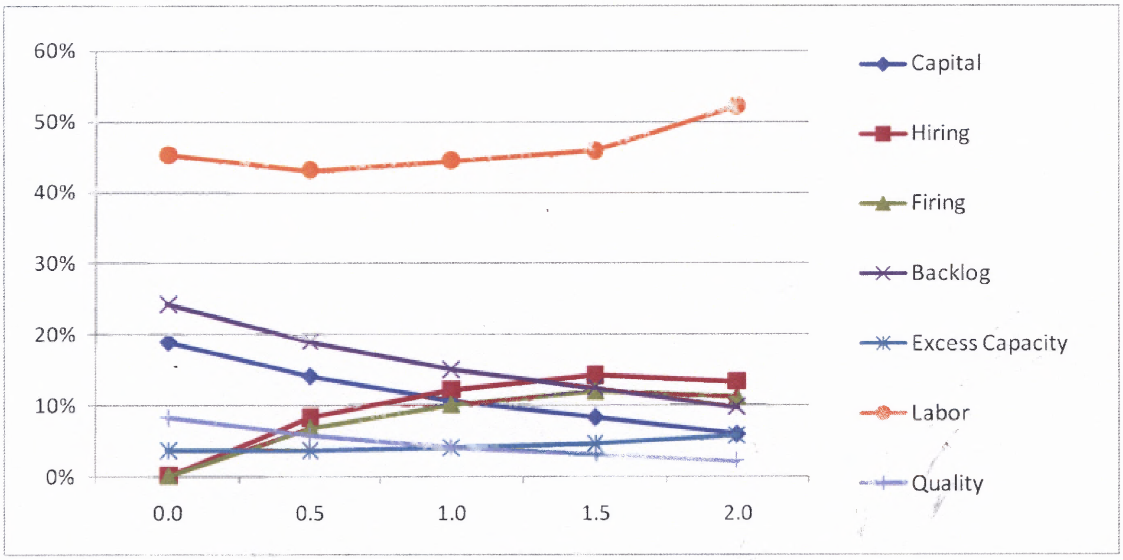



**Figure 6.5** Change in the weight of each cost factor for experiment 1.

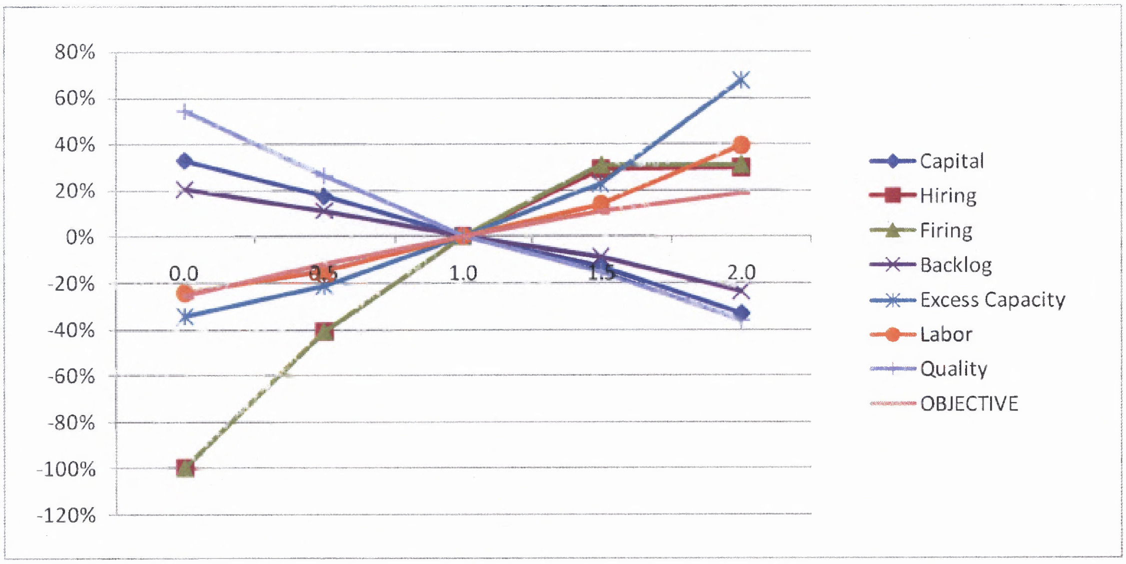



**Figure 6.6** Change in the contribution of different cost elements.

**Table 6.9** Contrast of Optimal Solution when *f*=2 with Solution when *f*=0.

| f=2 | Optimal | Solution f=0 | |
|---|---|---|---|
| Capital | $ 7,131,694 | $ 14,190,098 | |
| Hiring | $ 16,056,315 | $ 34,606,366 | |
| Firing | $ 13,433,484 | $ 28,875,556 | |
| Backlog | $ 11,603,211 | $ 18,300,300 | |
| Excess Capacity | $ 6,842,295 | $ 2,685,298 | |
| Labor | $ 62,996,510 | $ 34,152,151 | |
| Quality | $ 2,544,779 | $ 6,166,953 | |
| **OBJECTIVE** | $ 120,608,288 | $ 138,976,722 | **15%** |

## 6.4 Analysis of Task 7 as an Illustration

The assignment of task 7 for different levels of *f* was analyzed as an illustration of how the model assigns tasks under different conditions. To perform the analysis, the contribution to the objective function of the facilities capable of performing task 7 was compared when only that task was assigned to them. The facility with the minimum contribution and the facility that was actually selected at different *f* levels were identified (Figure 6.7).

The facility with the minimum contribution to the objective function for task 7 was not necessarily the facility selected. The model considers the contribution to the objective function of the facilities after all the tasks have been assigned, and not each task in isolation. The comparison of the contributions is presented in Table 6.10. The model considers all the services, tasks, and facilities to reach the minimum value of the objective function.

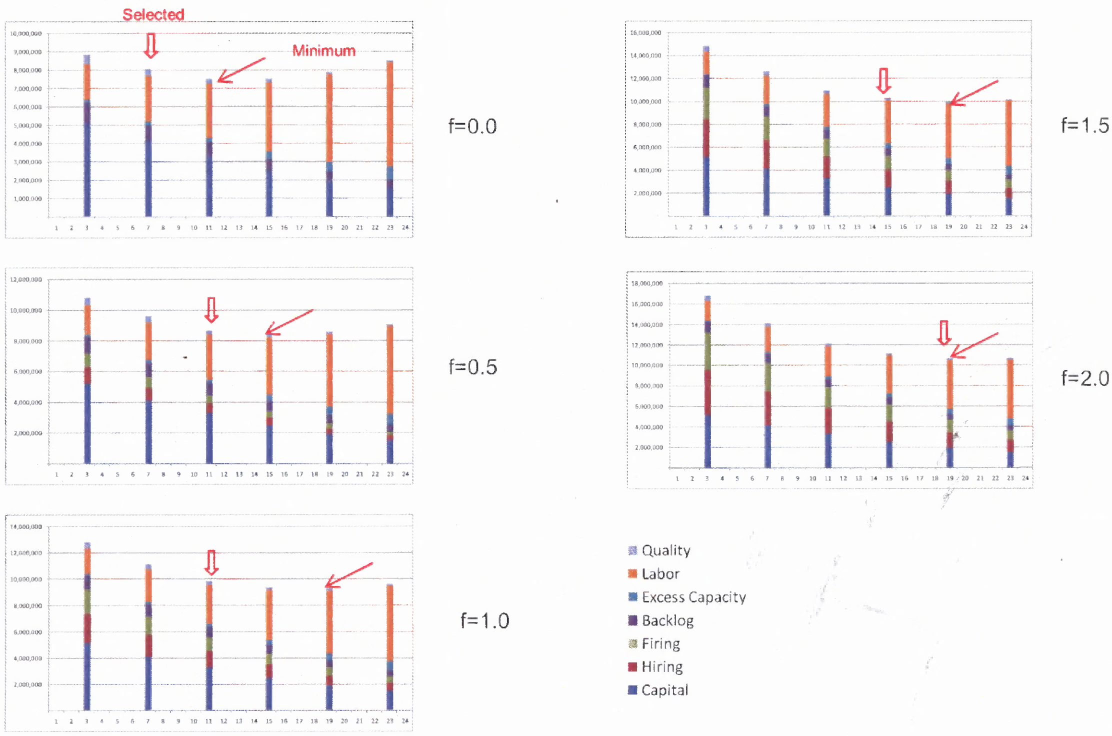



**Figure 6.7** Cost contribution of task 7 to objective function.

**Table 6.10** Comparison of the Contribution to the Objective Function for Task 7

| | Facility | | | |
|---|---|---|---|---|
| f | Best for Task 7 | $ | Selected | $ |
| 0 | 11 | 1,879,916 | 7 | 2,014,192 |
| 0.5 | 15 | 2,110,002 | 11 | 2,167,047 |
| 1 | 19 | 2,321,900 | 11 | 2,454,179 |
| 1.5 | 19 | 2,493,249 | 15 | 2,568,494 |
| 2 | 19 | 2,664,597 | 19 | 2,664,597 |

## 6.5 Experiment 2: Varying Demand

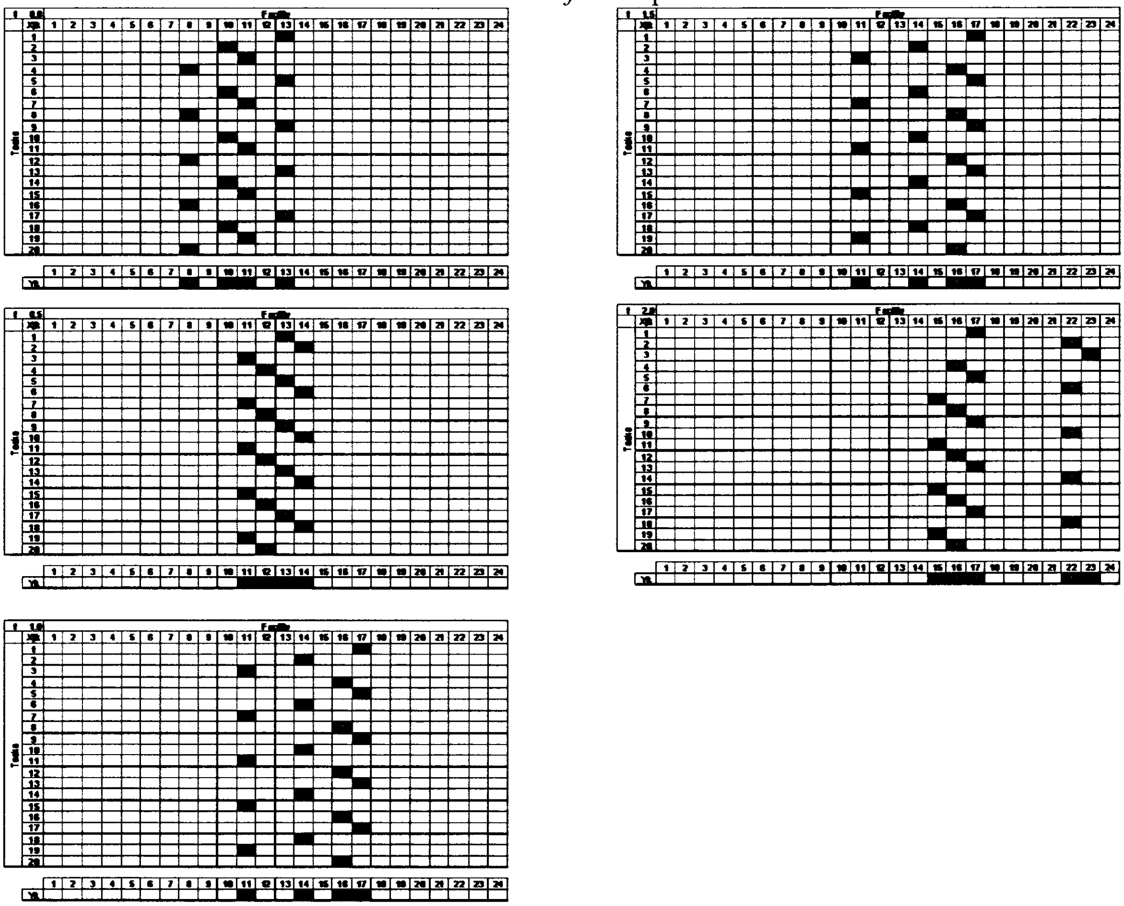
This experiment was designed to show how the model reacts to changes in the range of demand variability. A factor *f* was used to multiply the cyclical index $S_i$. It was changed from 0 to 2 in intervals of .5—*f*=1is the original problem. The different results were registered and analyzed. Table 6.11 and Figure 6.8 present the effect of the experiment on the objective function and in each of the cost components for the different solutions. Table 6.12 presents the solution for different values of *f*, including facilities selected to perform each task and the facilities that will be part of the Service Supply Chain at different ranges of demand variability.

**Table 6.11** Cost Components for Different Solutions in Experiment 2

| Factor | 0 | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Capital | $ 13,360,200 | $ 11,891,465 | $ 10,692,557 | $ 10,692,557 | $ 10,377,374 |
| Hiring | $ 2,126,501 | $ 7,832,905 | $ 12,373,493 | $ 17,711,799 | $ 18,286,004 |
| Firing | $ - | $ 5,676,716 | $ 10,250,049 | $ 15,375,074 | $ 16,444,792 |
| Backlog | $ 17,636,628 | $ 16,297,286 | $ 15,223,721 | $ 15,223,721 | $ 12,943,325 |
| Excess Capacity | $ - | $ 1,744,996 | $ 4,094,231 | $ 6,141,346 | $ 11,265,738 |
| Labor | $ 36,052,501 | $ 40,661,713 | $ 45,215,951 | $ 45,215,951 | $ 54,871,252 |
| Quality | $ 5,538,119 | $ 4,620,198 | $ 3,997,615 | $ 3,997,615 | $ 3,050,811 |
| OBJECTIVE | $ 74,713,949 | $ 88,725,279 | $ 101,847,617 | $ 114,358,063 | $ 127,239,296 |

In this experiment, no facility is dominant for any task. As demand variability increases, the model selects facilities with lower hiring and firing cost, and higher labor cost. Hiring and firing costs and labor cost increase in absolute value, as well as the objective function value, as shown in Figure 6.8. However, Figure 6.9 shows that the relative contribution of labor cost to the objective function fluctuates between 40%-48%. It also shows that as the relative values of hiring, firing, and excess capacity increase, the ones for backlog, capital, and quality decrease.

**Table 6.12** Solutions for Different Values of $f$ in Experiment 2



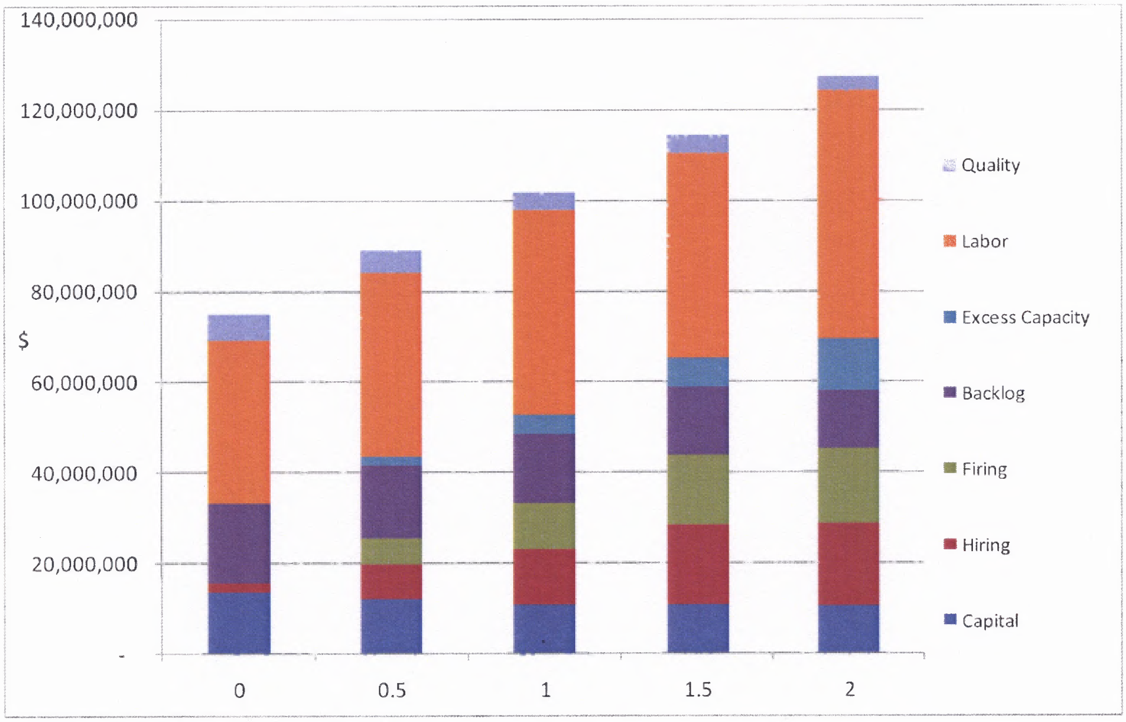



**Figure 6.8** Contribution of different cost component in experiment 2.

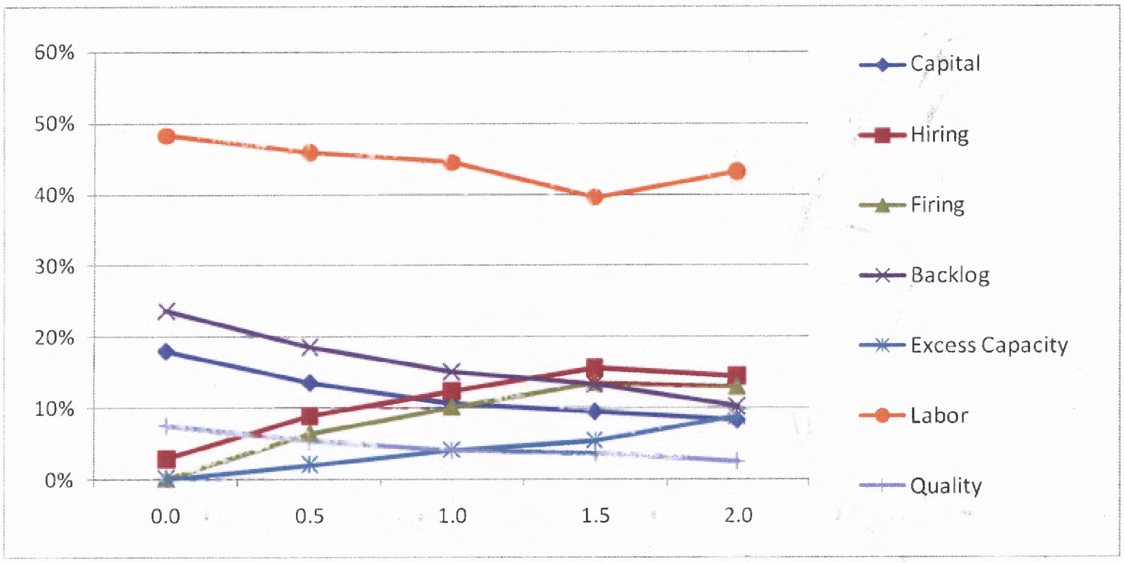



**Figure 6.9** Change in the weight of each cost factor for experiment 2.

## 6.6 Experiment 3: Varying Labor Cost

This experiment was designed to show how the model reacts to variations in the labor cost. A factor *f* was used to multiply the labor cost ($L_k$). It was changed from 0 to 2 in intervals of .5—*f*=1is the original problem. The different results were registered and analyzed. Table 6.13 and Figure 6.10 present the effect of the experiment in the objective function and in each of the cost components for the different solutions. Table 6.14 presents the solutions for different values of *f*, including the facilities selected to perform each task and the facilities that will be part of the Service Supply Chain at different levels of labor cost.

**Table 6.13** Cost Components for Different Solutions in Experiment 3

| Factor | 0 | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Capital | $ 6,428,249 | $ 7,131,694 | $ 10,692,557 | $ 13,360,200 | $ 14,055,443 |
| Hiring | $ 6,772,837 | $ 8,028,158 | $ 12,373,493 | $ 15,581,082 | $ 16,203,332 |
| Firing | $ 5,684,813 | $ 6,716,742 | $ 10,250,049 | $ 12,932,629 | $ 13,478,122 |
| Backlog | $ 10,663,576 | $ 11,603,211 | $ 15,223,721 | $ 17,636,628 | $ 18,259,568 |
| Excess Capacity | $ - | $ 3,421,148 | $ 4,094,231 | $ 4,401,408 | $ 5,476,231 |
| Labor | $ - | $ 31,498,255 | $ 45,215,951 | $ 54,078,751 | $ 69,245,498 |
| Quality | $ 1,602,519 | $ 2,258,197 | $ 3,997,615 | $ 5,835,490 | $ 6,471,937 |
| OBJECTIVE | $ 31,151,994 | $ 70,657,404 | $ 101,847,617 | $ 123,826,189 | $ 143,190,132 |

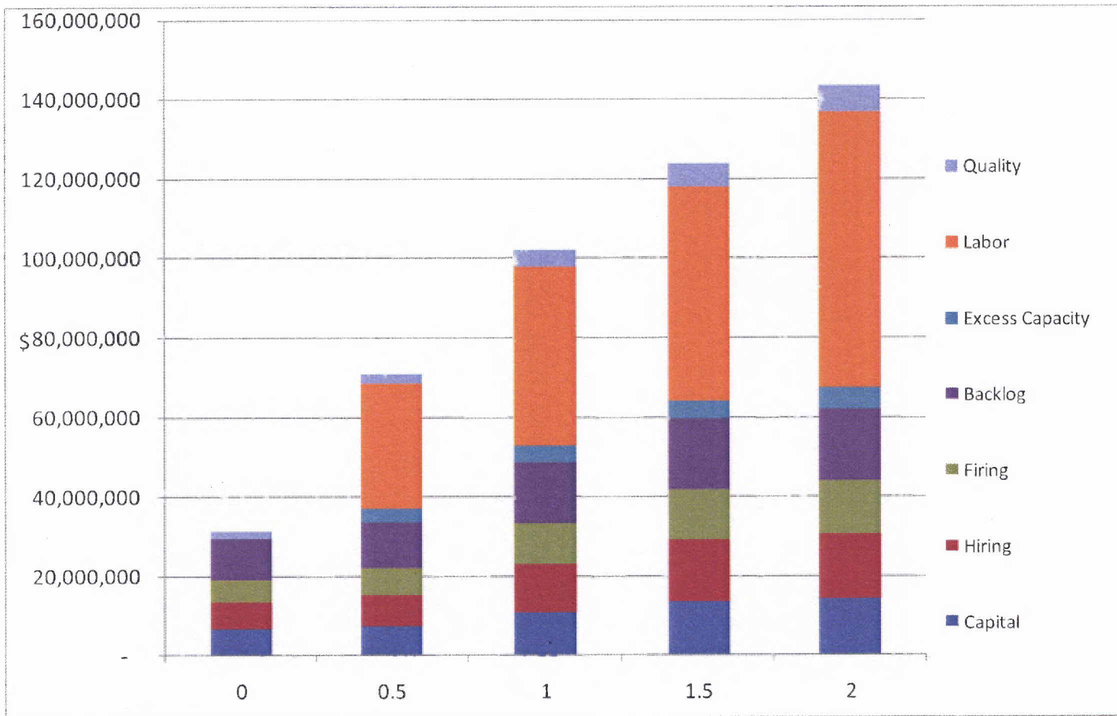



**Figure 6.10** Contribution of different cost component in experiment 3.

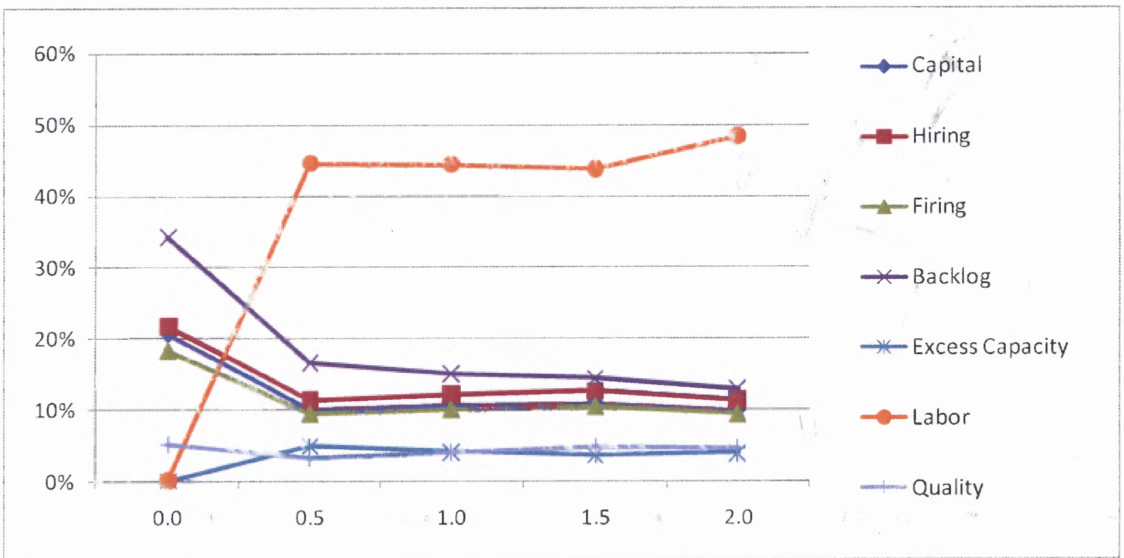
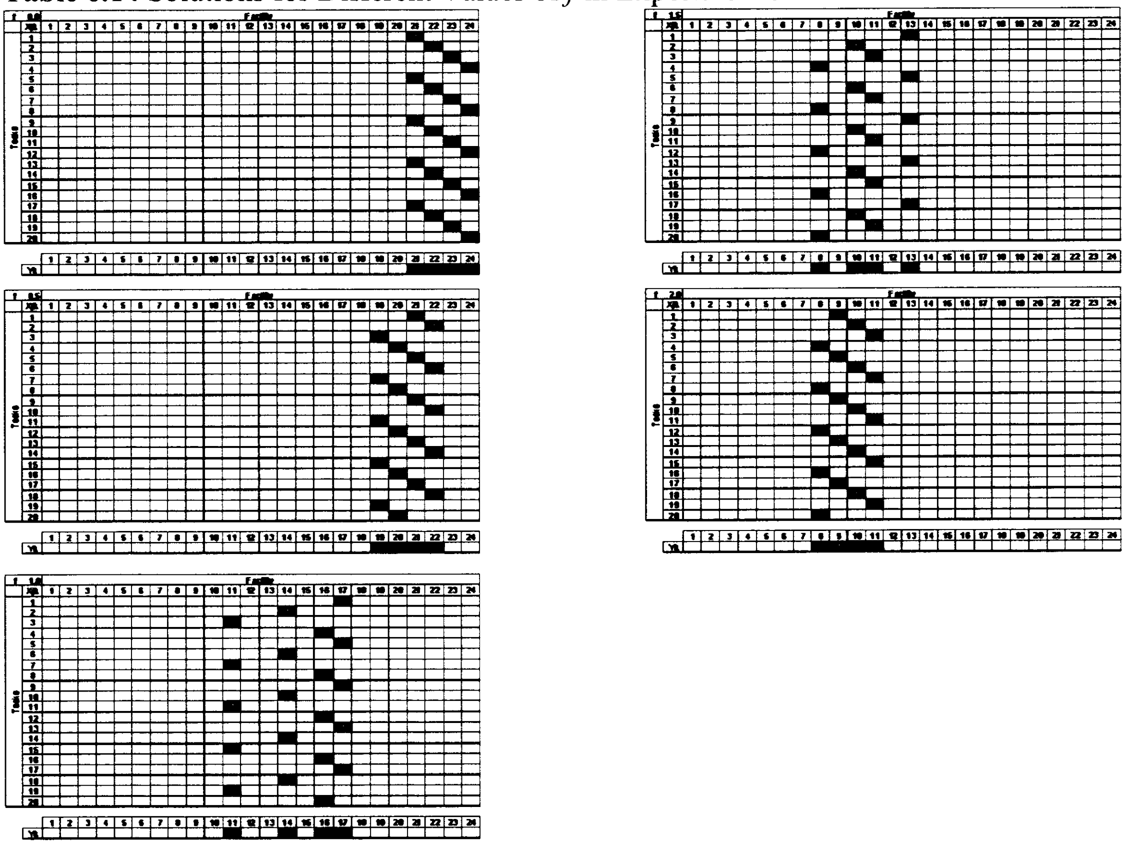



**Figure 6.11** Change in the weight of each cost factor for experiment 3.

**Table 6.14** Solutions for Different Values of $f$ in Experiment 3



In this experiment, as labor cost increases, the model selects facilities with lower labor cost and higher hiring and firing cost. The objective function value, as well as hiring, firing, and labor cost increase in absolute value as shown in Figure 6.10. However, Figure 6.11 shows that the relative contribution of each cost component of the objective function tends to be stable, except for the extreme case where $f$=0.

## 6.7 Heuristic Solution

In this section, a heuristic procedure to solve the problem was designed and the solution compared with the solution of the mathematical programming model. Since the main resource is labor, the heuristic was based on lowering labor cost. The procedure is as follows:

1. For each task, identify the facilities capable of performing it.
2. Select the facility with lower labor cost and assign the task to it.
3. Repeat for each task.
4. After all the tasks have been assigned, verify that the solution is feasible, by solving the capacity constraint (equation (4.48)).

$$G_k \geq \sum_{j=1}^{m} \frac{X_{jk}}{W_j P_k} \sum_{i=1}^{n} \left( R_{ij} \left( a_i T + b_i + \left( a_i \frac{T}{2} + b_i \right) \frac{S_i}{2} \right) \right)$$

5. If the capacity constraint is violated for a certain facility, assign one task to the facility with the next lower cost, and repeat until all the tasks have been assigned and the capacity constraint is satisfied.

The heuristic procedure yields an objective function value 28% higher than the result reached with the mathematical model. (See Table 6.15, Table 6.16, and Figure 6.12).

**Table 6.15** Heuristic Solution

| | | Facility | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Xjk | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Tasks | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 13 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 14 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 15 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 16 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 17 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 18 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 19 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 20 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yk | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 6.16** Contrast of Heuristic Solution and Mathematical Programming Solution

| | Model | Heuristic | Diff |
|---|---|---|---|
| Capital | $ 10,692,557 | $ 21,604,553 | 102% |
| Hiring | $ 12,373,493 | $ 26,219,155 | 112% |
| Firing | $ 10,250,049 | $ 21,561,077 | 110% |
| Backlog | $ 15,223,721 | $ 24,287,472 | 60% |
| Excess Capacity | $ 4,094,231 | $ 1,540,042 | -62% |
| Labor | $ 45,215,951 | $ 24,102,418 | -47% |
| Quality | $ 3,997,615 | $ 10,628,725 | 166% |
| OBJECTIVE | **$ 101,847,617** | **$ 129,943,441** | **28%** |

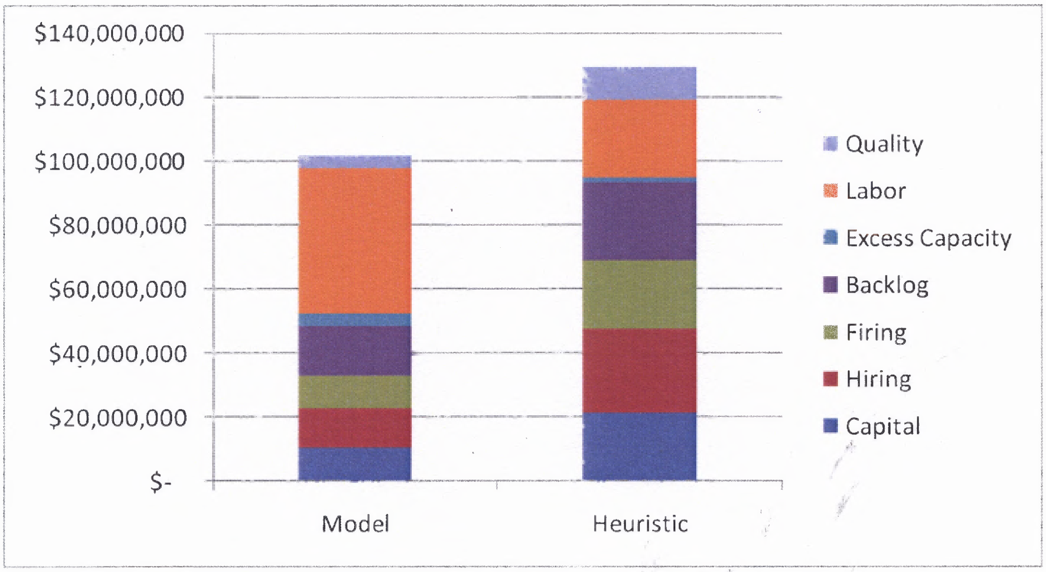



**Figure 6.12** Contrast of heuristic solution and mathematical programming solution.

## 6.8 Contrast of Heuristic Solution with Mathematical Model

In this section, the results provided by the heuristic procedure when performing experiment 1 to experiment 3 (sections 6.3 to 6.6), were contrasted and compared with the results obtained through mathematical programming.

Figure 6.13 and Table 6.17 show the relative difference in the cost elements and the objective function value, between the heuristic and the mathematical programming model when performing experiment 1—variying $H_k$ and $F_k$. Figure 6.14 shows the absolute difference. Since the labor cost does not change in the experiment, the solution provided by the heuristic does not change either—$X_{jk}$ and $Y_k$. However, the value of the objective function does change due to the change in the parameters. Even when the labor cost and the excess capacity component are lower when using the heuristic, the rest of the cost components and the objective function value are significantly higher for all values of $f$. The mathematical programming model outperforms the heuristic by up to 47%. As $H_k$ and $F_k$ are higher across the chain the benefits of using the strategic model increase.

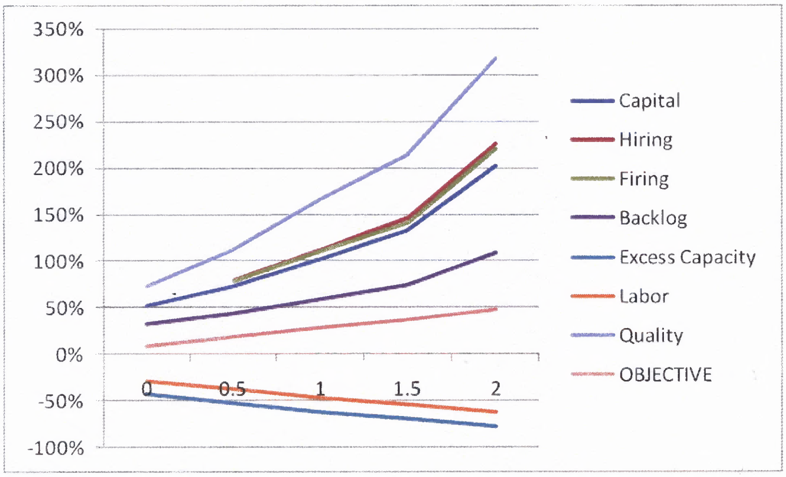



**Figure 6.13** Relative difference for experiment 1.

**Table 6.17** Relative Difference for Experiment 1

| Factor | 0 | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Capital | 52% | 72% | 102% | 133% | 203% |
| Hiring | | 80% | 112% | 146% | 227% |
| Firing | | 78% | 110% | 141% | 221% |
| Backlog | 33% | 44% | 60% | 75% | 109% |
| Excess Capacity | -43% | -52% | -62% | -69% | -77% |
| Labor | -29% | -37% | -47% | -53% | -62% |
| Quality | 72% | 111% | 166% | 214% | 318% |
| OBJECTIVE | 9% | 18% | 28% | 37% | 47% |

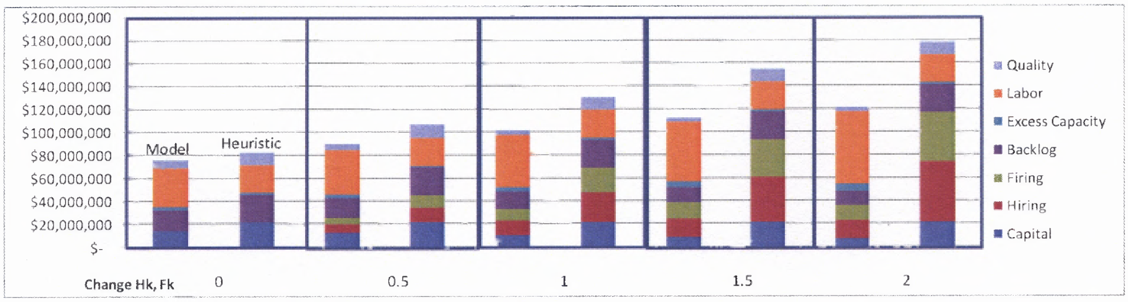



**Figure 6.14** Absolute difference for experiment 1.

Figure 6.15 and Table 6.18 show the relative difference in the cost elements and the objective function value, between the heuristic and the mathematical programming model when performing experiment 2—variying $S_i$. Figure 6.16 shows the absolute difference. Since the labor cost does not change in the experiment, the solution provided by the heuristic does not change either—$X_{jk}$ and $Y_k$. However, the value of the objective function does change due to the consequent increase in the number of hiring and firing events and the effect on backlog and excess capacity. Even when the labor cost and the excess capacity component are lower when using the heuristic, the rest of the cost components and the objective function value are significantly higher for all values of $f$. The mathematical programming model outperforms the heuristic by up to 38%. As the range of demand variability $S_i$ is larger, the benefits of using the strategic model increase.

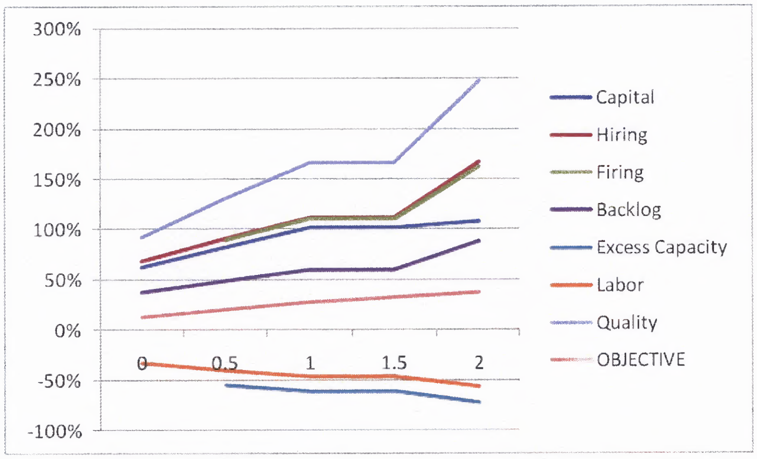



**Figure 6.15** Relative difference for experiment 2.

**Table 6.18** Relative Difference for Experiment 2

| Factor | 0 | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Capital | 62% | 82% | 102% | 102% | 108% |
| Hiring | 68% | 90% | 112% | 112% | 167% |
| Firing | | 90% | 110% | 110% | 162% |
| Backlog | 38% | 49% | 60% | 60% | 88% |
| Excess Capacity | | -56% | -62% | -62% | -73% |
| Labor | -33% | -41% | -47% | -47% | -56% |
| Quality | 92% | 130% | 166% | 166% | 248% |
| OBJECTIVE | 13% | 21% | 28% | 34% | 38% |

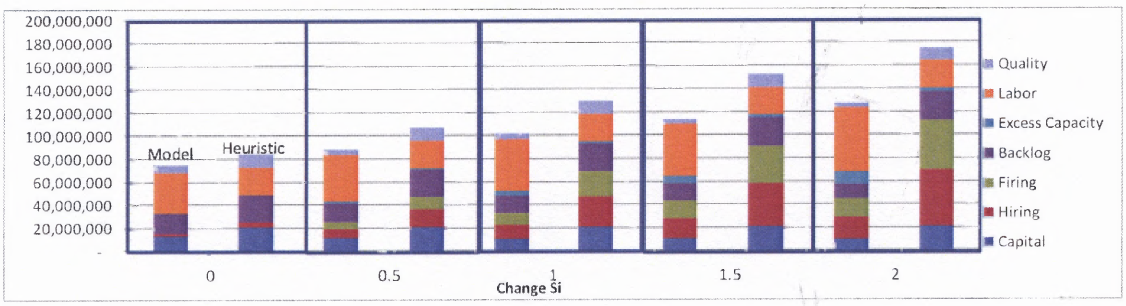



**Figure 6.16** Absolute difference for experiment 2.

Figure 6.17 and Table 6.19 show the relative difference in the cost elements and the objective function value, between the heuristic and the mathematical programming model when performing experiment 3—variying $L_k$. Figure 6.18 shows the absolute difference. Since the labor cost changes uniformly across the chain, the solution provided by the heuristic does not change—$X_{jk}$ and $Y_k$. However, the value of the objective function does change due to the change in labor cost. Even when the labor cost and the excess capacity component are lower when using the heuristic, the rest of the cost components and the objective function value are significantly higher for all values of $f$. The mathematical programming model outperforms the heuristic by up to 66%. As the labor cost increases and is more significant, the difference in the results from the heuristic and the strategic model decrease but are still significant.

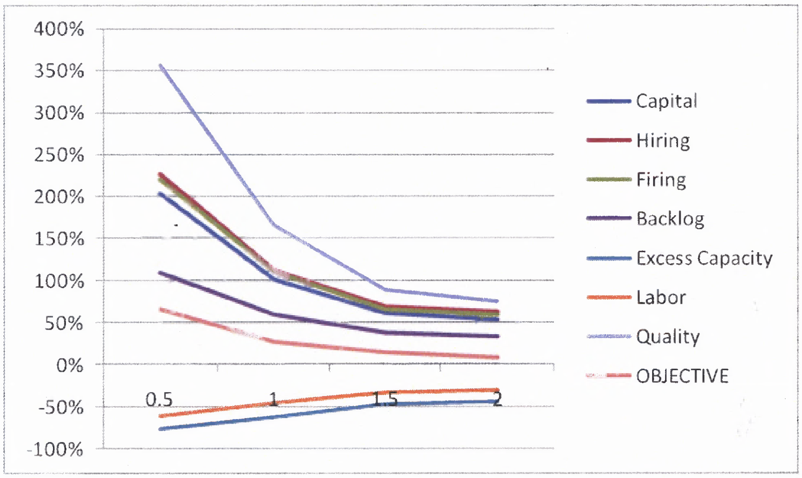



**Figure 6.17** Relative difference for experiment 3.

**Table 6.19** Relative Difference for Experiment 3

| Factor | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|
| Capital | 203% | 102% | 62% | 54% |
| Hiring | 227% | 112% | 68% | 62% |
| Firing | 221% | 110% | 67% | 60% |
| Backlog | 109% | 60% | 38% | 33% |
| Excess Capacity | -77% | -62% | -48% | -44% |
| Labor | -62% | -47% | -33% | -30% |
| Quality | 356% | 166% | 88% | 74% |
| OBJECTIVE | 65% | 28% | 16% | 9% |

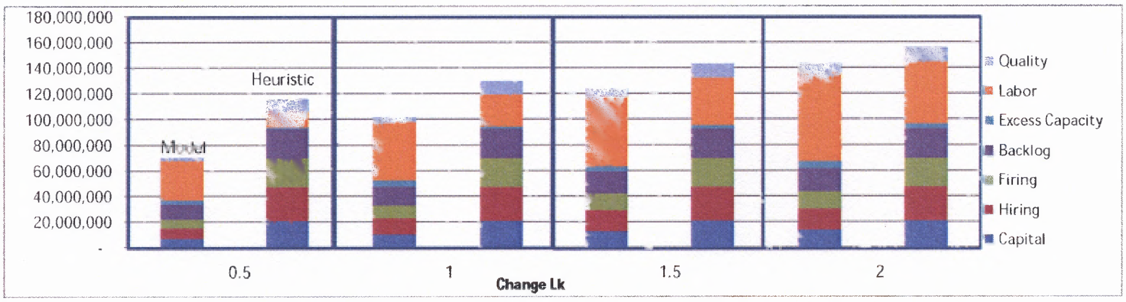



**Figure 6.18** Absolute difference for experiment 3.

## 6.9 Conclusions

In this section, the conclusions derived from the numerical experiments with the strategic model are presented. In the example, the parameters for the competing facilities are in opposition—facilities with lower labor cost have higher hiring and firing cost—as illustrated in Figure 6.2. After performing the numerical experiments the following conclusions were reached:

- The model can be solved using software and hardware available currently in the market. A solution was reached in 6.5 seconds.
- When hiring and firing cost ($H_k$ and $F_k$) increase across the chain, the model selects facilities with higher labor cost and lower relative $H_k$ and $F_k$.
- The model evaluates the chain as a whole. Even when the selection of certain facilities does not yield the lowest cost for an individual task, it yields the lowest cross for the whole Service Supply Chain.
- When demand variability ($S_i$) increases, the model selects facilities with lower relative hiring and firing cost $H_k$ and $F_k$.
- When labor cost increases across the chain ($L_k$), the model selects facilities with lower relative labor cost and higher hiring and firing cost $H_k$ and $F_k$.

Contrasting the strategic model with a heuristic method based on lower labor cost, the following conclusions were reached:

- When varying $H_k$ and $F_k$ uniformly across the SSC the strategic model outperformed the heuristic by up to 47%. The heuristic selects the facilities with lower labor cost but the model considers all cost elements to make the decision.

- As $H_k$ and $F_k$ are higher across the chain the benefits of using the strategic model increase.

- When the range of demand variability $S_i$ varies, the strategic model outperforms the heuristic by up to 38%. As $S_i$ becomes larger, the benefits of using the strategic model increase.

- When varying $L_k$ uniformly across the SSC the strategic model outperformed the heuristic by up to 66%. As labor cost increases and is a more significant share of the objective function cost, the difference in the results from the heuristic and the strategic model decrease but are still significant.

- The model evaluates the Service Supply Chain as a whole and takes into account different parameters to make the decision. Therefore, it will yield better decisions than any localized method, or a method that uses only one cost—as is the case of the heuristic.

# CHAPTER 7

# NUMERICAL EXPERIMENTS WITH THE TACTICAL MODEL

This chapter presents the numerical experiments performed to achieve research objective number 4, to analyze the strategic and tactical models and several case studies to assess the validity and utility of the models. Several case studies were designed and experiments performed. There are two main objectives for the numerical experiments:

- To determine the computational feasibility of the models, verifying that the models can be solved using available software and hardware.
- To evaluate how the model behaves when the backlog cost changes.

The tactical level model will make decisions regarding production planning and the allocation of resources to different service products. The tactical model will prescribe the workforce level at each service location to dynamically match the current service demand rate. Numerical experiments with the strategic and tactical models will be performed to assess their validity and utility.

## 7.1 Problem Setting and Numerical Solution

This section presents an example problem to illustrate the tactical model. Given the conditions established by the strategic model, and a more accurate demand forecast, the tactical model determines the workforce level required at each service provider to satisfy demand at the lower cost.

In the numerical problem, the Service Supply Chain provides four service products. Each service product requires the completion of up to eight tasks among 20 tasks performed by the Service Supply Chain. The different service products share at least one task with other products (Figure 6.1). The sample demand is derived from the Mortgage Applications Indexes (unadjusted) from January 2000 to December 2004. The planning horizon is 71 time periods, with one lead in period (arrivals=0), service request arrivals for about 60 periods and there are 8 to 10 lead out (arrivals=0) periods per service (Table 7.1). The model is run twice, first as an LP and then as a MIP model. The LP model yields a result in 10.91 seconds with an objective function value of $5,780,152. The MIP model yields a solution in 10.90 seconds with an objective function value of $5,781,511. The different parameters are derived from the strategic model solution. It has the following total of 1192 decision variables in each run:

- $X_{kt}$: Number of servers at facility $k$ in period $t$. Dimension: 4x71=284
- $Y_{ijt}$: Completion rate for task $j$ in period $t$ for service $i$. Dimension 340 with 8 dummies (receiving and delivering).
- $O_{kt}$: Hiring at facility $k$ in period $t$. Dimension: 4x71=284
- $U_{kt}$: Firing at facility $k$ in period $t$ Dimension: 4x71=284

**Table 7.1** Arrivals for Tactical Model Numerical Example

| | Periods | | |
|---|---|---|---|
| Service | Lead in | Arrivals | Lead Out |
| 1 | 1 | 60 | 10 |
| 2 | 1 | 60 | 10 |
| 3 | 1 | 62 | 8 |
| 4 | 1 | 61 | 9 |

The objective function value and its cost components are shown in Table 7.2 and Figure 7.1. A graphical representation of the arrivals for each service is provided in Figure 7.2. The solutions for $X_{kj}$ are represented in Figure 7.3. The hiring events for each facility are presented in Figure 7.4. The firing events for each facility are shown in Figure 7.5. The backlogs for each service are presented in Figures 7.6 to 7.9. In the numerical example the hiring and firing cost for each selected facility are high when compared to the backlog cost. Therefore, the model tries to minimize hirings and firings and result in a high number of backlog units especially for service 4, the one with the lower backlog cost. However, because the backlog cost per service is low, the total backlog cost represents only 11% of the objective function value. Experiments setting the backlog cost at different levels were performed to analyze the behavior.

**Table 7.2** Objective Function Value for Tactical Model Numerical Example

| Cost | Amount ($) |
|---|---|
| Hire | 1,369,420 |
| Fire | 1,316,099 |
| Labor | 2,441,778 |
| Backlog | 654,213 |
| **Objective** | **5,781,511** |

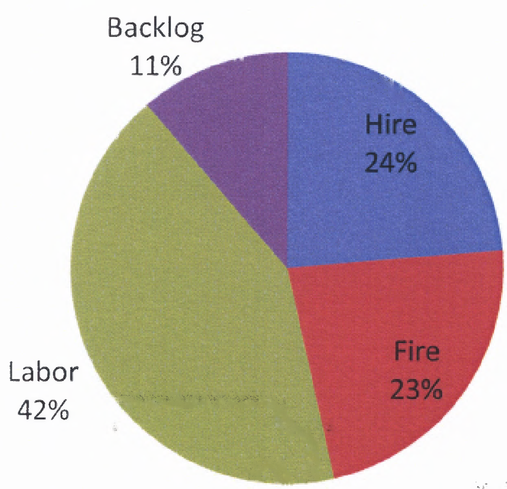



**Figure 7.1** Cost components for tactical model numerical example.

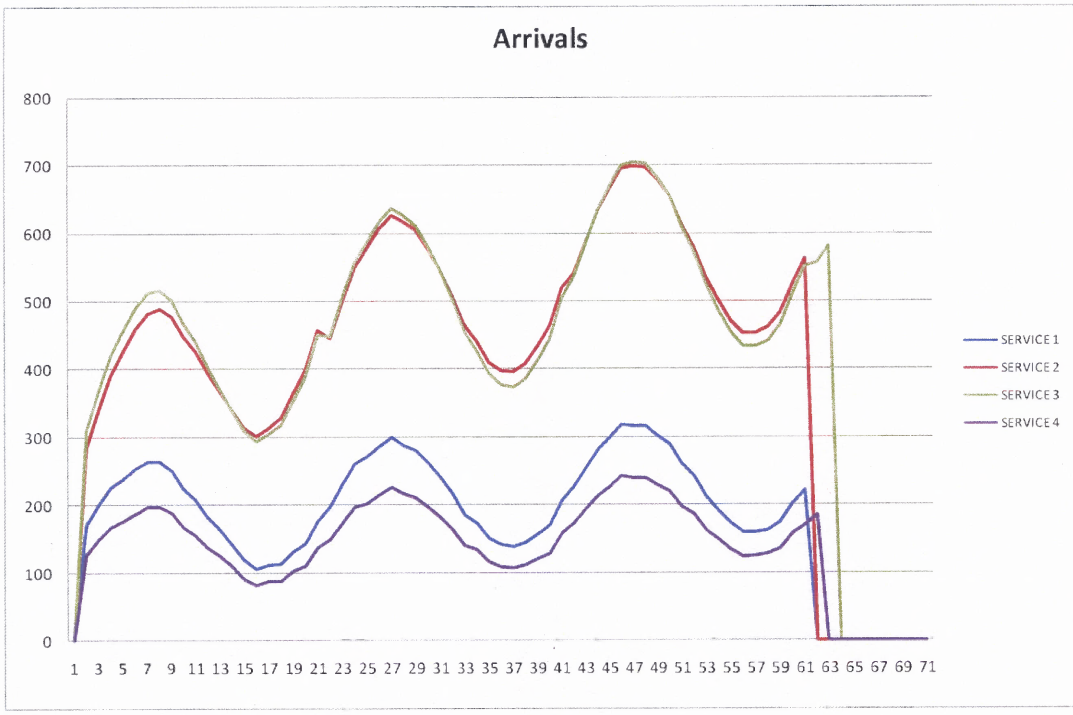



**Figure 7.2** Arrivals for tactical model numerical example.

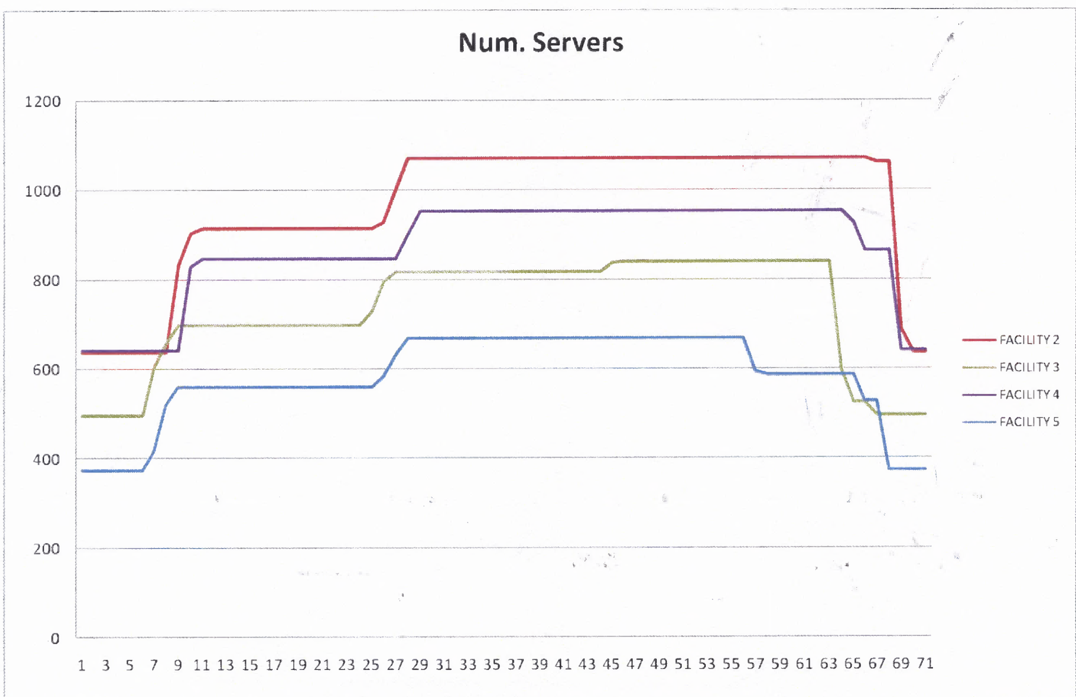



**Figure 7.3** Number of servers ($X_{kj}$) for tactical model numerical example


**Figure 7.4** Hiring ($O_{kt}$) for tactical model numerical example.

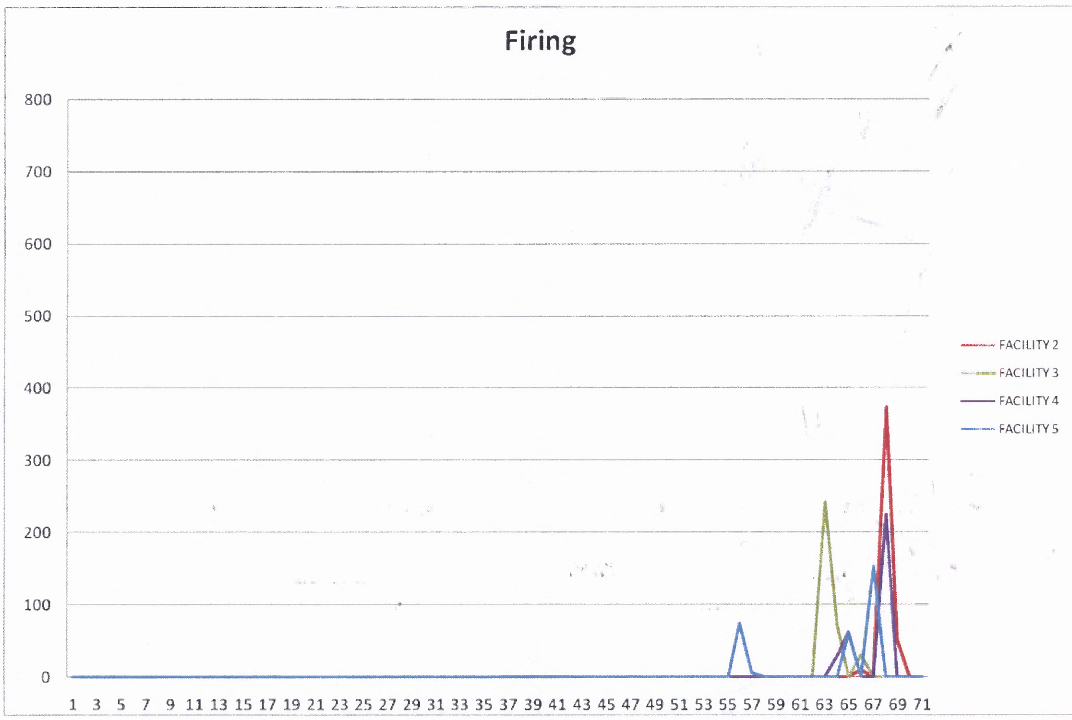



**Figure 7.5** Firing ($U_{kt}$) for tactical model numerical example.

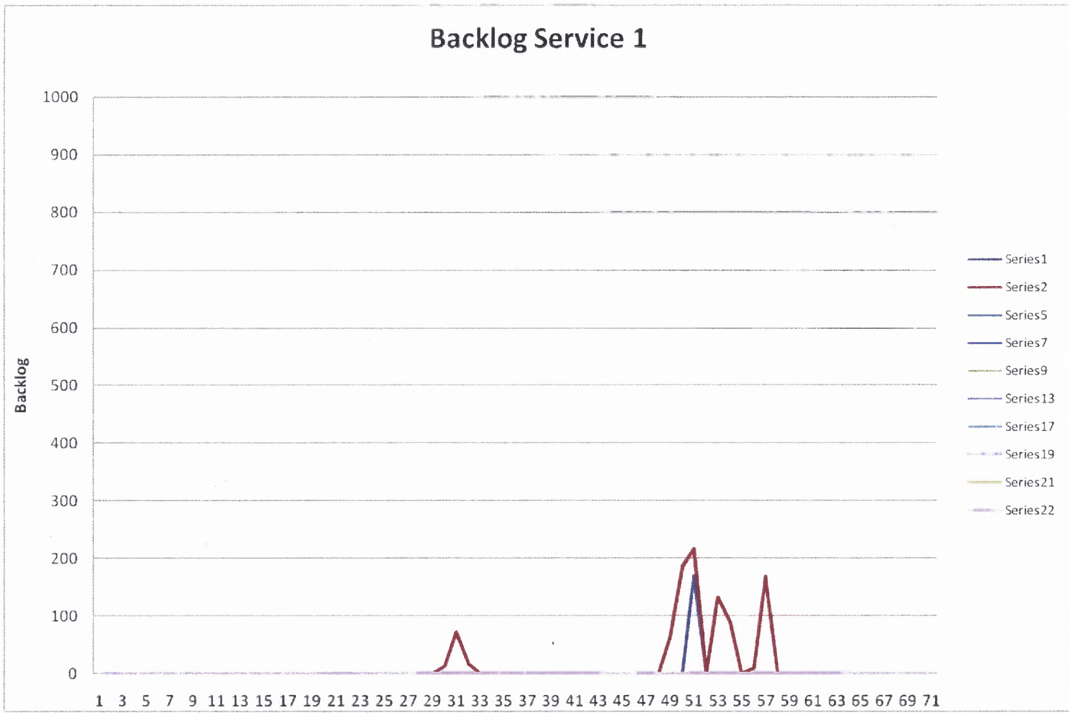



**Figure 7.6** Backlog for service 1 ($B_{1jt}$).

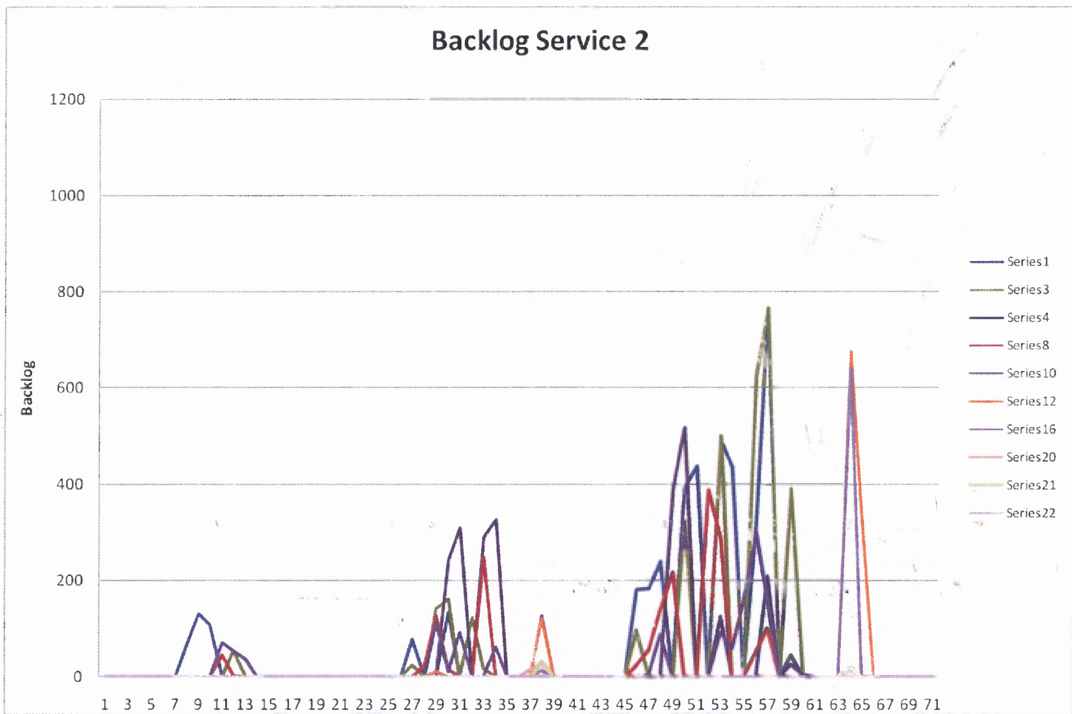



**Figure 7.7** Backlog for service 2 ($B_{2jt}$).

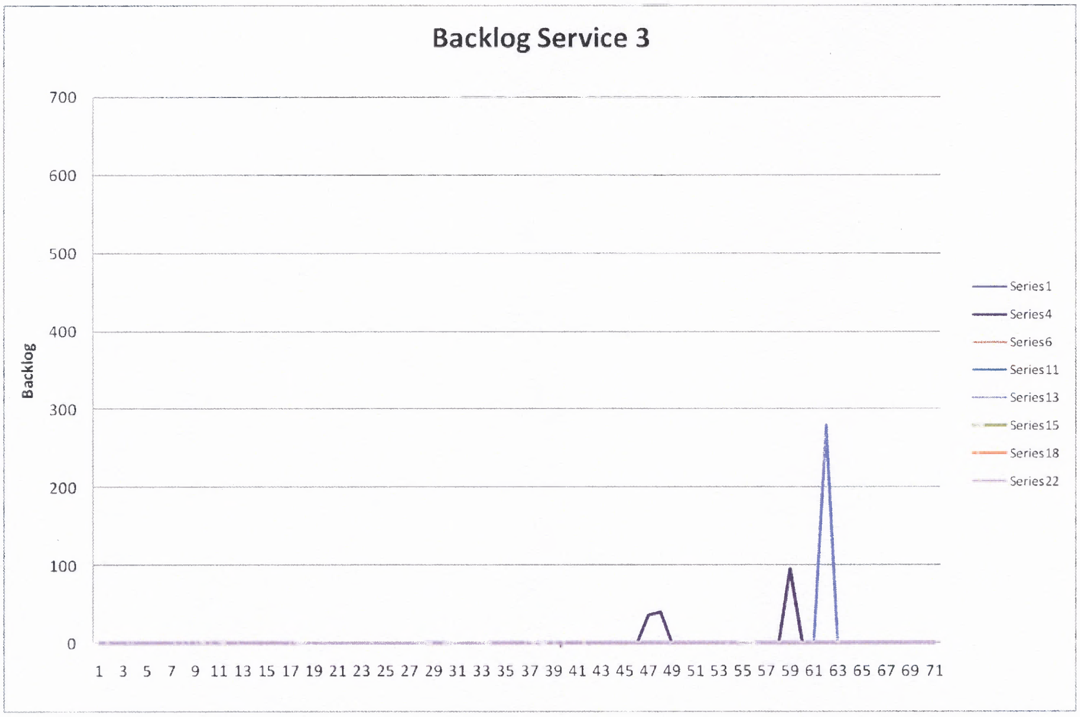



**Figure 7.8** Backlog for service 3 ($B_{3jt}$).

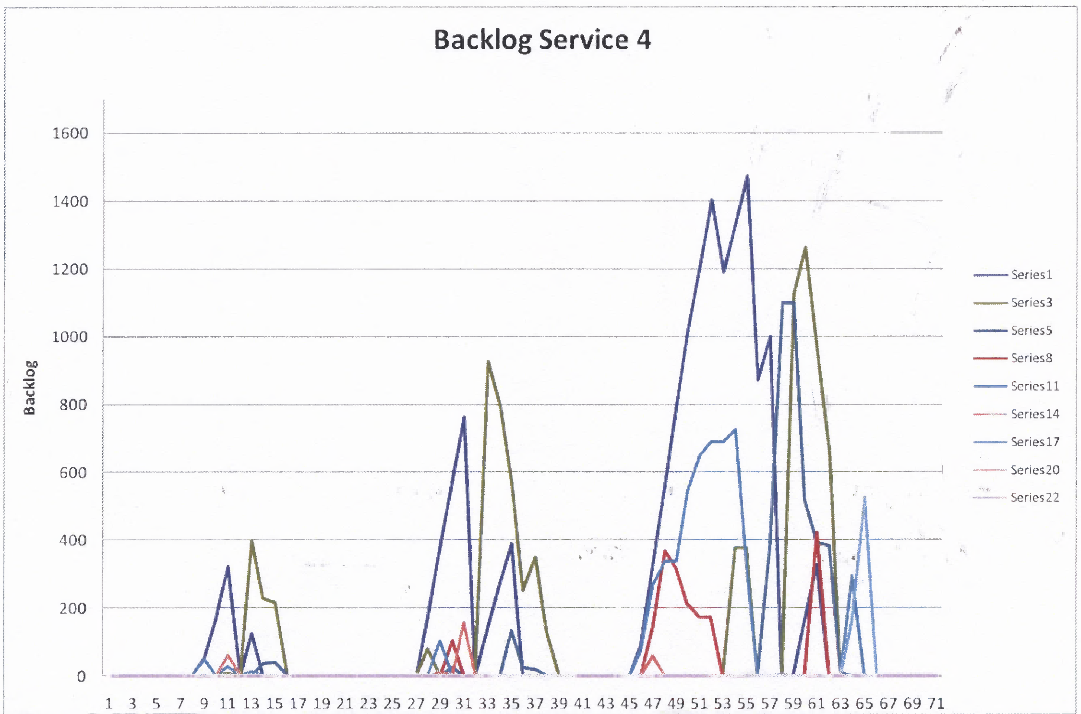



**Figure 7.9** Backlog for service 4 ($B_{4jt}$).

## 7.2 Experiment Varying Backlog Cost

The experiment was designed to show how the tactical model reacts to variations in the backlog cost. A factor $f$ was used to multiply the backlog cost ($E_i$). It was changed from 0.5 to 1.5 in intervals of .5—$f$=0.5 represent a reduction of 50% in the backlog cost per unit, $f$=1 is the original problem, $f$=1.5 represent an increase of 50% in the backlog cost per unit.

### 7.2.1 Contrast between $f$=0.5 and $f$=1

Table 7.3 presents the difference in the objective function and in each of the cost components. The objective function value was reduced by 7% and the total backlog cost was reduced by 15%. However, total backlog measured in units delayed increased 43%. Figure 7.10 presents the difference in number of servers ($X_{kj}$). During most of the run the number of servers is lower for $f$=0.5 except towards the end. This is a result of both experiments having the same ending conditions. Figure 7.11 shows the periods where the number of hiring is lower in $f$=0.5. Figure 7.12 shows that the firing events are similar except towards the end. Figures 7.13 to 7.16 show the difference in backlogs.

**Table 7.3** Difference in Objective Function between $f$=1 and $f$=0.5

| Cost | % |
|---|---|
| Hire | -9% |
| Fire | -9% |
| Labor | -2% |
| Backlog | -15% |
| **Objective** | **-7%** |

| | |
|---|---|
| Backlog Units | 43% |

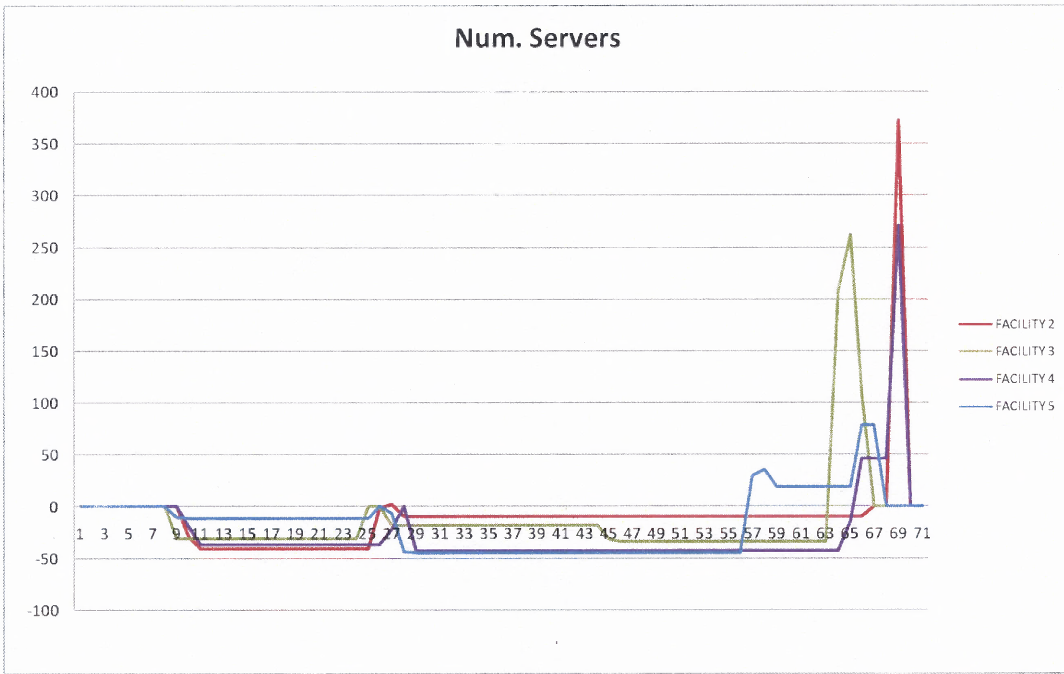



**Figure 7.10** Difference in number of servers ($X_{kj}$) between $f$=1 and $f$=0.5.


**Figure 7.11** Difference in hiring ($O_{kt}$) between $f$=1 and $f$=0.5.

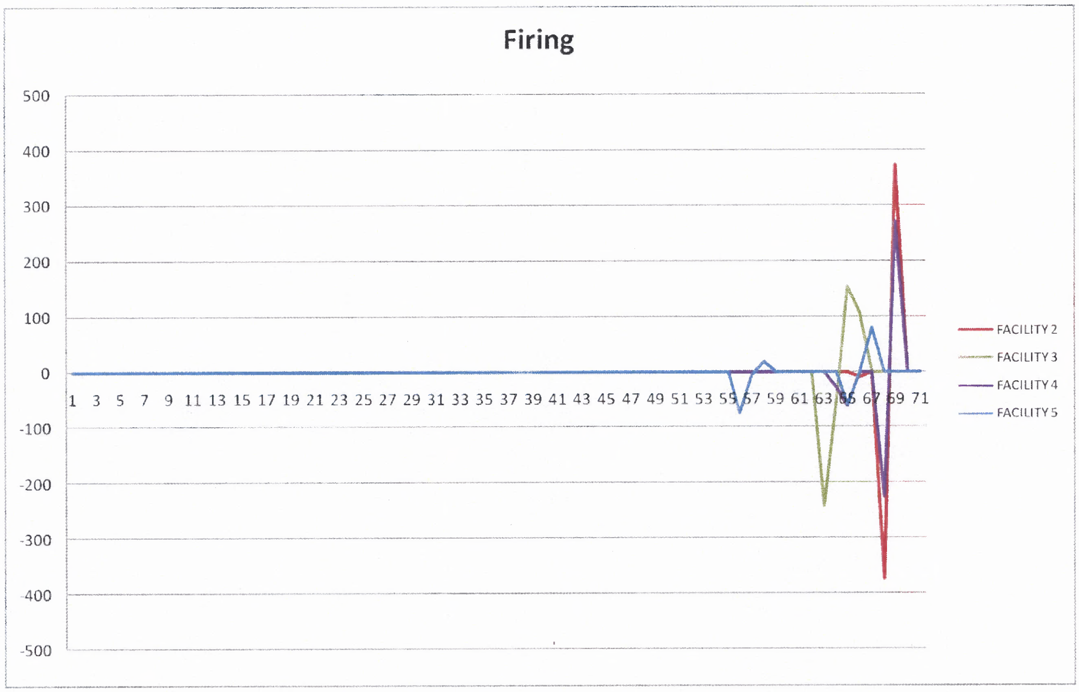



**Figure 7.12** Difference in firing ($U_{kt}$) between $f$=1 and $f$=0.5.

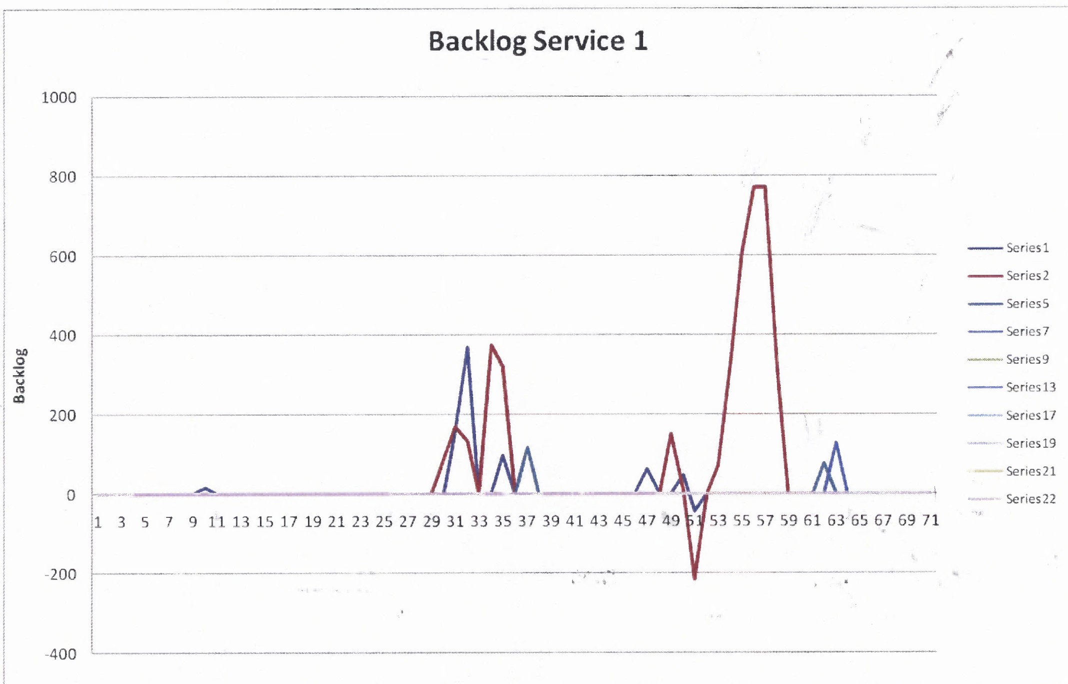



**Figure 7.13** Difference in backlog for service 1 ($B_{1jt}$) between $f$=1 and $f$=0.5.

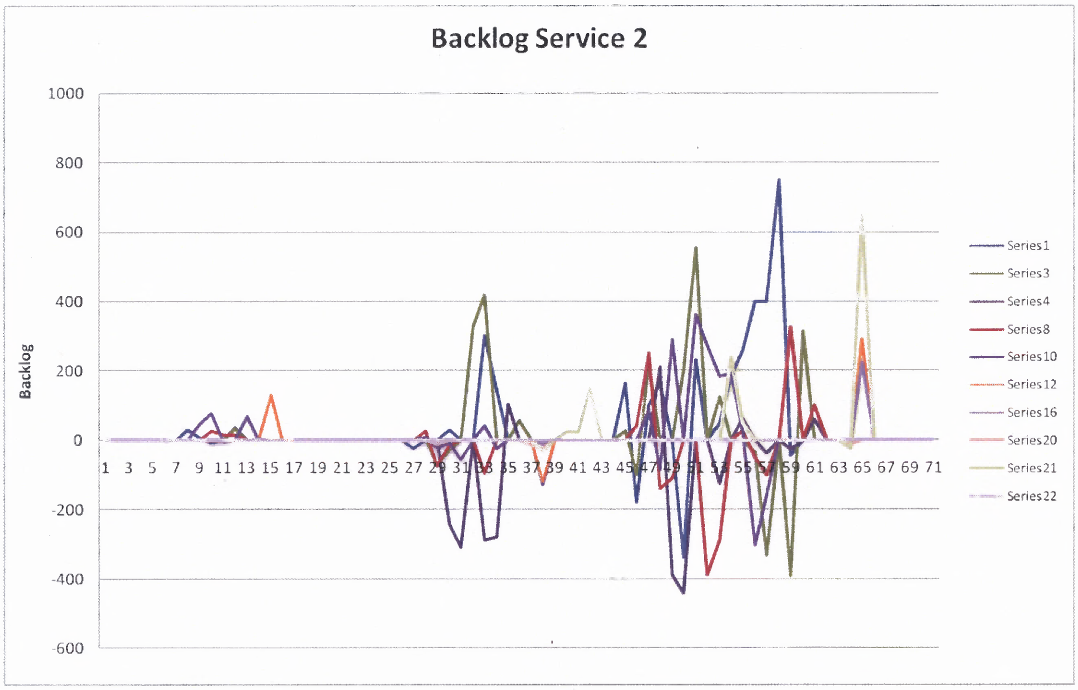



**Figure 7.14** Difference in backlog for service 2 ($B_{2jt}$) between $f$=1 and $f$=0.5.

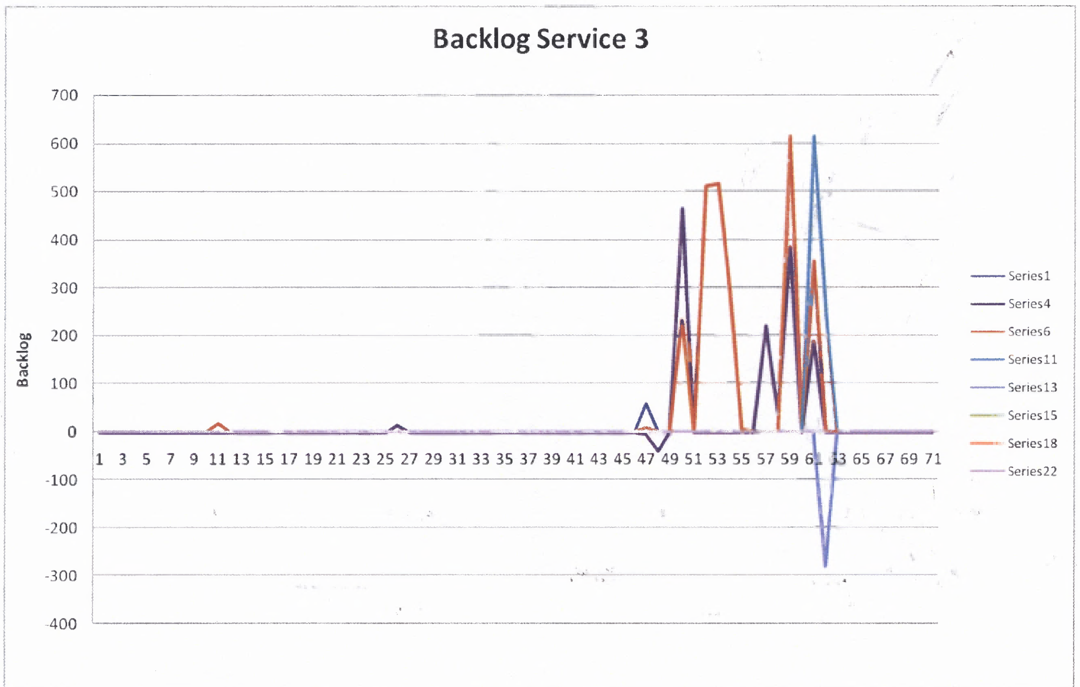



**Figure 7.15** Difference in backlog for service 3 ($B_{3jt}$) between $f$=1 and $f$=0.5.

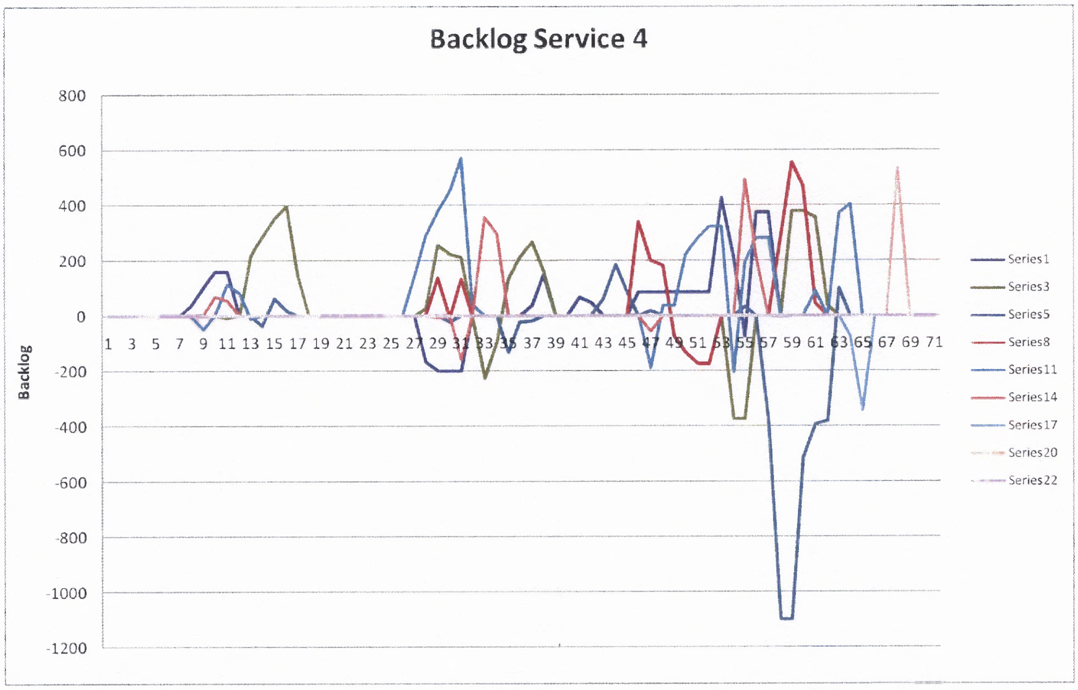



**Figure 7.16** Difference in backlog for service 4 ($B_{4jt}$) between $f$=1 and $f$=0.5.

### 7.2.2 Contrast between $f$=1.5 and $f$=1

Table 7.4 presents the difference in the objective function and in each of the cost components. The objective function value was increased by 5% and the total backlog cost was reduced by 5%. Total backlog measured in units delayed decreased 35%. Figure 7.17 presents the difference in number of servers ($X_{kj}$). During most of the run the number of servers is higher for $f$=1.5 except towards the end. This is a result of both experiments having the same ending conditions. Figure 7.18 shows the periods where the number of hiring is higher in $f$=1.5. Figure 7.19 shows that the firing events are similar except towards the end. Figures 7.20 to 7.23 show the difference in backlogs.

**Table 7.4** Difference in Objective Function between $f$=1 and $f$=1.5

| Cost | % |
|---|---|
| Hire | 9% |
| Fire | 9% |
| Labor | 2% |
| Backlog | -5% |
| **Objective** | **5%** |

| | |
|---|---|
| Backlog Units | -35% |

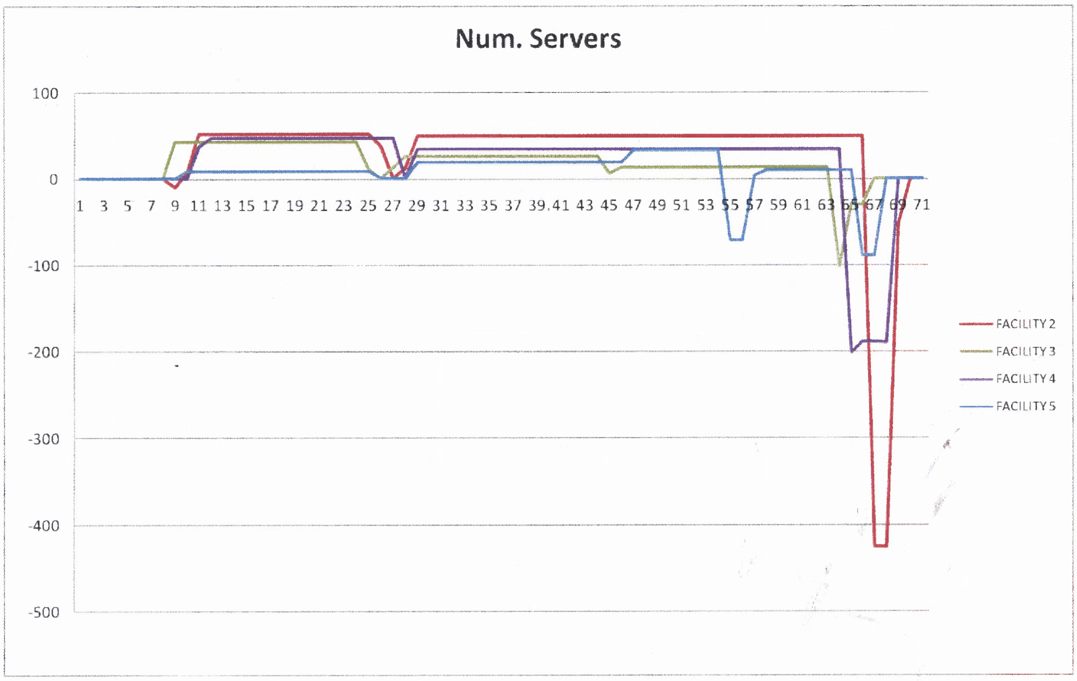



**Figure 7.17** Difference in number of servers ($X_{kj}$) between $f$=1 and $f$=1.5.


**Figure 7.18** Difference in hiring ($O_{kt}$) between $f$=1 and $f$=1.5.

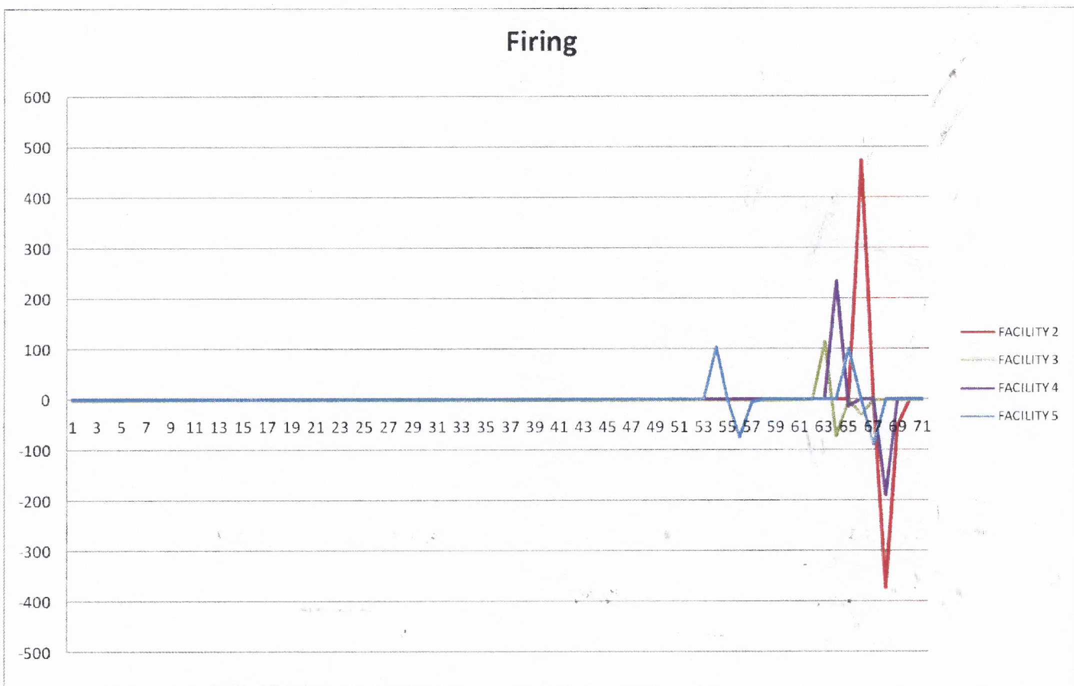



**Figure 7.19** Difference in firing ($U_{kt}$) between $f$=1 and $f$=1.5.


**Figure 7.20** Difference in backlog for service 1 ($B_{1jt}$) between $f$=1 and $f$=1.5.

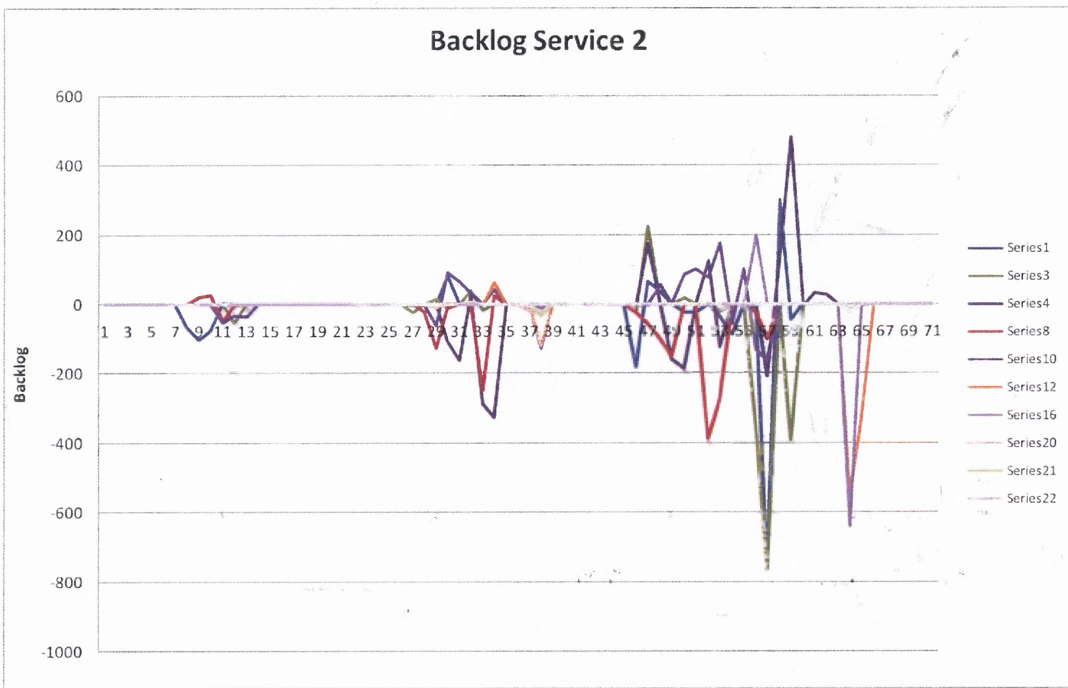



**Figure 7.21** Difference in backlog for service 2 ($B_{2jt}$) between $f$=1 and $f$=1.5.

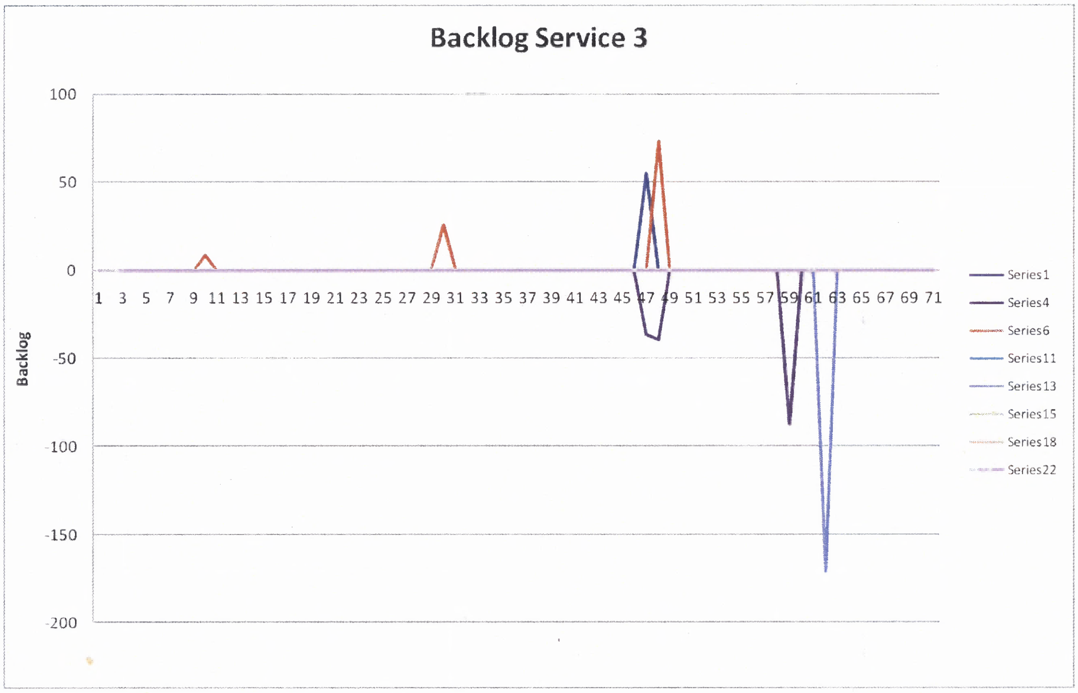



**Figure 7.22** Difference in backlog for service 3 ($B_{3jt}$) between $f$=1 and $f$=1.5.

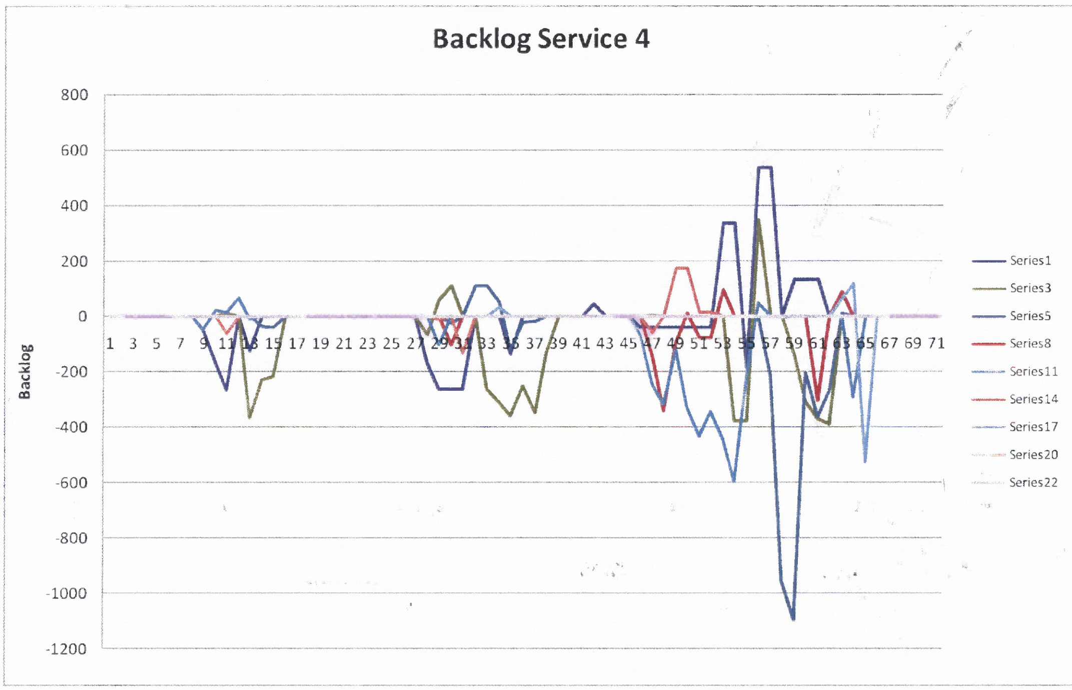



**Figure 7.23** Difference in backlog for service 4 ($B_{4jt}$) between $f$=1 and $f$=1.5.

## 7.3 Conclusions

In this section, the conclusions derived from the numerical experiments with the tactical model are presented. In the example, demand is shared by all SCC members and the capacity in all the service facilities is coordinated centrally. After performing the numerical experiments the following conclusion were reached:

- The model can be solved using software and hardware available currently in the market. A solution was reached in 10.91 seconds for the LP problem and in 10.90 seconds for the MIP.
- When the backlog cost ($B_{ijt}$) decreases for all services, the model lowers the number of servers in all the service facilities and the number of service jobs delayed increases.
- When the backlog cost ($B_{ijt}$) increases for all services, the model increases the number of servers in all the service facilities and the number of service jobs delayed decreases.

## 7.4 Further Research

One important insight of this dissertation is that the main service provider is able to establish a SSC with flexible capacity that can be adjusted according to changes in demand. Capacity can be managed in real time from a centralized point to reduce cost and manage backlogs. However, the models have their limitations that signal avenues for further research:

- The strategic and tactical models assume constant parameters for probability of poor quality, hire, fire and labor cost, productivity, response time, and backlog cost. It is necessary to develop models that consider stochastic elements and uncertainties in these parameters.
- The strategic model assigns each task to only one facility, it would be interesting to study the models when this constraint is relaxed and each tasks can be assigned to more than one facility.
- Analyze the sensitivity of the tactical model when actual demand varies from the expected demand used to make strategic decisions.

- Perform longer scale experiments to analyze the relationship between hiring and firing cost and the probability of backlog.
- Develop simulations and compare their results with the mathematical model.
- Develop Dynamic Programming models and compare their results with the MIP results.
- Conduct empirical research to determine current practices for capacity management in SSC and calibrate the models.

# APPENDIX: HOW TO DETERMINE DEMAND PARAMETERS

Several methods could be used to forecast demand; however, the forecast will be inaccurate due to the long-term horizon. At the strategic level, the objective of the demand forecast is to quantify the expected demand variation. At this level, an accurate forecast of demand for a specific time period is not relevant. The interest here is to quantify the variation per seasonal cycle and growth trend. The following parameters are determined:

$a_i$: slope of demand curve for service $i$.

$b_i$: Intercept of demand curve for service $i$.

$T$: Number of periods (months) in the planning horizon

$S_i$: Average range of the cyclical index.

$\tau_i$: Average length of seasonal cycles.

Once the demand for the planning horizon has been forecasted (for example by using classic time-series decomposition), is necessary to smooth or rearrange the forecast to quantify total increase and total decrease in demand per seasonal cycle. The following method determines the parameters necessary to quantify demand variation:

- Using the forecasted demand for the strategic planning horizon, follow the next steps for each seasonal cycle.
- Calculate the variation for each cycle.

$$\Delta D(t)=D(t)-D(t-1) \qquad \text{(A. 1)}$$

Where $\Delta D(t)$ is the variation of demand for cycle $t$, and $D(t)$ is demand for cycle $t$

- Determine if the seasonal cycle starts with a positive or negative growth trend.

$$\Delta D(1)>0 \qquad \text{(A. 2)}$$

- Sort the variation in decreasing order if the seasonal cycle starts with a growth trend (increasing order if it starts with a negative growth trend)
- Recalculate the forecast using the rearranged differences.
- For each seasonal cycle, calculate the maximum, minimum, and range.
- For the forecasting horizon, calculate the average seasonal maximum, the average seasonal minimum, and the average seasonal range.
- For the rearranged forecast, calculate the growth intercept, slope, and average; with that information calculate the seasonal index $S_i$.

Here is an example:

Step 1: Forecast demand for the strategic planning horizon

**Table A.1** Example Forecasted Demand

| Month | Forecast | Month | Forecast | Month | Forecast | Month | Forecast | Month | Forecast |
|---|---|---|---|---|---|---|---|---|---|
| Dec-04 | 3,062 | | | | | | | | |
| **Jan-05** | **7,697** | Jan-06 | 8,756 | **Jan-07** | **9,816** | Jan-08 | 10,875 | **Jan-09** | **11,935** |
| **Feb-05** | **8,721** | Feb-06 | 9,922 | **Feb-07** | **11,122** | Feb-08 | 12,323 | **Feb-09** | **13,523** |
| **Mar-05** | **11,082** | Mar-06 | 12,608 | **Mar-07** | **14,133** | Mar-08 | 15,659 | **Mar-09** | **17,184** |
| **Apr-05** | **7,828** | Apr-06 | 8,906 | **Apr-07** | **9,983** | Apr-08 | 11,061 | **Apr-09** | **12,139** |
| **May-05** | **8,388** | May-06 | 9,543 | **May-07** | **10,697** | May-08 | 11,852 | **May-09** | **13,007** |
| **Jun-05** | **9,038** | Jun-06 | 10,283 | **Jun-07** | **11,527** | Jun-08 | 12,771 | **Jun-09** | **14,015** |
| **Jul-05** | **7,762** | Jul-06 | 8,831 | **Jul-07** | **9,899** | Jul-08 | 10,968 | **Jul-09** | **12,036** |
| **Aug-05** | **7,774** | Aug-06 | 8,844 | **Aug-07** | **9,915** | Aug-08 | 10,985 | **Aug-09** | **12,055** |
| **Sep-05** | **8,369** | Sep-06 | 9,521 | **Sep-07** | **10,674** | Sep-08 | 11,826 | **Sep-09** | **12,978** |
| **Oct-05** | **9,768** | Oct-06 | 11,112 | **Oct-07** | **12,457** | Oct-08 | 13,802 | **Oct-09** | **15,146** |
| **Nov-05** | **8,809** | Nov-06 | 10,022 | **Nov-07** | **11,235** | Nov-08 | 12,448 | **Nov-09** | **13,660** |
| **Dec-05** | **6,179** | Dec-06 | 7,030 | **Dec-07** | **7,880** | Dec-08 | 8,731 | **Dec-09** | **9,582** |

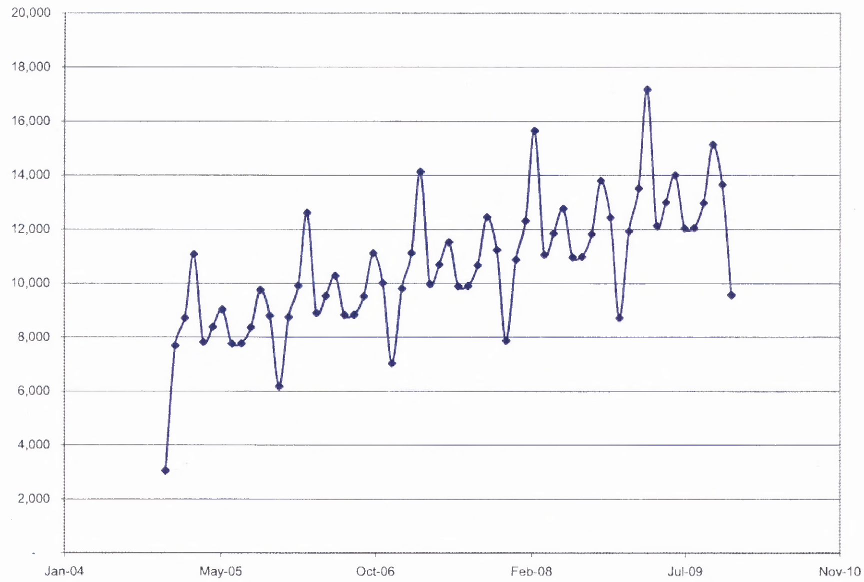



**Figure A.1** Example of forecasted demand.

Table A.1 shows forecasted demand for a service product for five years. Figure A.1 shows that the forecasted demand has seasonal and growth components. Each seasonal period (year) presents several increases and decreases in demand that affect the capacity required by the chain. The interest is in the cumulative increase and cumulative decrease in demand for the period and they will be determined from the forecast.

Step 2: Calculate the variation for each cycle. $\Delta D(t)$

**Table A.2** Variation in Forecasted Demand $\Delta D(t)$

| Month | Forecast | $\Delta D(t)$ | Month | Forecast | $\Delta D(t)$ | Month | Forecast | $\Delta D(t)$ |
|---|---|---|---|---|---|---|---|---|
| Dec-04 | 3,062 | | | | | | | |
| Jan-05 | 7,697 | 4,634 | Jan-06 | 8,756 | 2,577 | Jan-07 | 9,816 | 2,786 |
| Feb-05 | 8,721 | 1,024 | Feb-06 | 9,922 | 1,165 | Feb-07 | 11,122 | 1,306 |
| Mar-05 | 11,082 | 2,361 | Mar-06 | 12,608 | 2,686 | Mar-07 | 14,133 | 3,011 |
| Apr-05 | 7,828 | (3,254) | Apr-06 | 8,906 | (3,702) | Apr-07 | 9,983 | (4,150) |
| May-05 | 8,388 | 560 | May-06 | 9,543 | 637 | May-07 | 10,697 | 714 |
| Jun-05 | 9,038 | 651 | Jun-06 | 10,283 | 740 | Jun-07 | 11,527 | 830 |
| Jul-05 | 7,762 | (1,276) | Jul-06 | 8,831 | (1,452) | Jul-07 | 9,899 | (1,628) |
| Aug-05 | 7,774 | 12 | Aug-06 | 8,844 | 14 | Aug-07 | 9,915 | 15 |
| Sep-05 | 8,369 | 595 | Sep-06 | 9,521 | 677 | Sep-07 | 10,674 | 759 |
| Oct-05 | 9,768 | 1,398 | Oct-06 | 11,112 | 1,591 | Oct-07 | 12,457 | 1,783 |
| Nov-05 | 8,809 | (958) | Nov-06 | 10,022 | (1,090) | Nov-07 | 11,235 | (1,222) |

| Month | Forecast | $\Delta D(t)$ | Month | Forecast | $\Delta D(t)$ | Month | Forecast | $\Delta D(t)$ |
|---|---|---|---|---|---|---|---|---|
| Dec-05 | 6,179 | (2,630) | Dec-06 | 7,030 | (2,993) | Dec-07 | 7,880 | (3,355) |

| Month | Forecast | $D_t$-$D_{t-1}$ | Month | Forecast | $D_t$-$D_{t-1}$ |
|---|---|---|---|---|---|
| Jan-08 | 10,875 | 2,995 | Jan-09 | 11,935 | 3,204 |
| Feb-08 | 12,323 | 1,447 | Feb-09 | 13,523 | 1,589 |
| Mar-08 | 15,659 | 3,336 | Mar-09 | 17,184 | 3,661 |
| Apr-08 | 11,061 | (4,598) | Apr-09 | 12,139 | (5,046) |
| May-08 | 11,852 | 791 | May-09 | 13,007 | 868 |
| Jun-08 | 12,771 | 919 | Jun-09 | 14,015 | 1,009 |
| Jul-08 | 10,968 | (1,803) | Jul-09 | 12,036 | (1,979) |
| Aug-08 | 10,985 | 17 | Aug-09 | 12,055 | 18 |
| Sep-08 | 11,826 | 841 | Sep-09 | 12,978 | 923 |
| Oct-08 | 13,802 | 1,976 | Oct-09 | 15,146 | 2,168 |
| Nov-08 | 12,448 | (1,354) | Nov-09 | 13,660 | (1,486) |
| Dec-08 | 8,731 | (3,717) | Dec-09 | 9,582 | (4,079) |

Step 3: Determine if the seasonal cycle starts with a positive or negative growth trend. $\Delta D(1)>0$. The first difference in Table A.2 for January 2005, indicates that the cycle starts with positive growth.

Step 4: Sort the variation in decreasing order if the seasonal cycle starts with a positive growth trend (increasing order if it starts with a negative growth trend). Since it starts with positive growth the differences are sorted in decreasing order each year. See Table A.3.

Step 5: Recalculate the forecast using the rearranged differences.

**Table A.3** Sorted Differences and Smoothed Forecast

| Month | Forecast | $\Delta D(t)$ | Sorted $\Delta D(t)$ | Smoothed Forecast |
|---|---|---|---|---|
| Dec-04 | 3,062 | | | |
| Jan-05 | 7,697 | 4,634 | 4,634 | 7,697 |
| Feb-05 | 8,721 | 1,024 | 2,361 | 10,058 |
| Mar-05 | 11,082 | 2,361 | 1,398 | 11,456 |
| Apr-05 | 7,828 | (3,254) | 1,024 | 12,480 |
| May-05 | 8,388 | 560 | 651 | 13,131 |
| Jun-05 | 9,038 | 651 | 595 | 13,726 |
| Jul-05 | 7,762 | (1,276) | 560 | 14,286 |
| Aug-05 | 7,774 | 12 | 12 | 14,298 |
| Sep-05 | 8,369 | 595 | (958) | 13,340 |
| Oct-05 | 9,768 | 1,398 | (1,276) | 12,063 |

| Month | Forecast | $\Delta D(t)$ | Sorted $\Delta D(t)$ | Smoothed Forecast |
|---|---|---|---|---|
| **Nov-05** | **8,809** | **(958)** | **(2,630)** | **9,433** |
| **Dec-05** | **6,179** | **(2,630)** | **(3,254)** | **6,179** |
| Jan-06 | 8,756 | 2,577 | 2,686 | 8,865 |
| Feb-06 | 9,922 | 1,165 | 2,577 | 11,442 |
| Mar-06 | 12,608 | 2,686 | 1,591 | 13,033 |
| Apr-06 | 8,906 | (3,702) | 1,165 | 14,199 |
| May-06 | 9,543 | 637 | 740 | 14,939 |
| Jun-06 | 10,283 | 740 | 677 | 15,616 |
| Jul-06 | 8,831 | (1,452) | 637 | 16,253 |
| Aug-06 | 8,844 | 14 | 14 | 16,266 |
| Sep-06 | 9,521 | 677 | (1,090) | 15,176 |
| Oct-06 | 11,112 | 1,591 | (1,452) | 13,724 |
| Nov-06 | 10,022 | (1,090) | (2,993) | 10,732 |
| Dec-06 | 7,030 | (2,993) | (3,702) | 7,030 |
| **Jan-07** | **9,816** | **2,786** | **3,011** | **10,041** |
| **Feb-07** | **11,122** | **1,306** | **2,786** | **12,827** |
| **Mar-07** | **14,133** | **3,011** | **1,783** | **14,610** |
| **Apr-07** | **9,983** | **(4,150)** | **1,306** | **15,917** |
| **May-07** | **10,697** | **714** | **830** | **16,746** |
| **Jun-07** | **11,527** | **830** | **759** | **17,505** |
| **Jul-07** | **9,899** | **(1,628)** | **714** | **18,219** |
| **Aug-07** | **9,915** | **15** | **15** | **18,234** |
| **Sep-07** | **10,674** | **759** | **(1,222)** | **17,012** |
| **Oct-07** | **12,457** | **1,783** | **(1,628)** | **15,385** |
| **Nov-07** | **11,235** | **(1,222)** | **(3,355)** | **12,030** |
| **Dec-07** | **7,880** | **(3,355)** | **(4,150)** | **7,880** |
| Jan-08 | 10,875 | 2,995 | 3,336 | 11,216 |
| Feb-08 | 12,323 | 1,447 | 2,995 | 14,211 |
| Mar-08 | 15,659 | 3,336 | 1,976 | 16,187 |
| Apr-08 | 11,061 | (4,598) | 1,447 | 17,635 |
| May-08 | 11,852 | 791 | 919 | 18,554 |
| Jun-08 | 12,771 | 919 | 841 | 19,395 |
| Jul-08 | 10,968 | (1,803) | 791 | 20,186 |
| Aug-08 | 10,985 | 17 | 17 | 20,203 |
| Sep-08 | 11,826 | 841 | (1,354) | 18,849 |
| Oct-08 | 13,802 | 1,976 | (1,803) | 17,046 |
| Nov-08 | 12,448 | (1,354) | (3,717) | 13,329 |
| Dec-08 | 8,731 | (3,717) | (4,598) | 8,731 |
| **Jan-09** | **11,935** | **3,204** | **3,661** | **12,392** |
| **Feb-09** | **13,523** | **1,589** | **3,204** | **15,596** |
| **Mar-09** | **17,184** | **3,661** | **2,168** | **17,764** |
| **Apr-09** | **12,139** | **(5,046)** | **1,589** | **19,353** |
| **May-09** | **13,007** | **868** | **1,009** | **20,362** |
| **Jun-09** | **14,015** | **1,009** | **923** | **21,284** |
| **Jul-09** | **12,036** | **(1,979)** | **868** | **22,152** |
| **Aug-09** | **12,055** | **18** | **18** | **22,171** |
| **Sep-09** | **12,978** | **923** | **(1,486)** | **20,685** |
| **Oct-09** | **15,146** | **2,168** | **(1,979)** | **18,706** |

| Month | Forecast | $\Delta D(t)$ | Sorted $\Delta D(t)$ | Smoothed Forecast |
|---|---|---|---|---|
| **Nov-09** | **13,660** | **(1,486)** | **(4,079)** | **14,627** |
| **Dec-09** | **9,582** | **(4,079)** | **(5,046)** | **9,582** |

Step 6: For each seasonal cycle, calculate the maximum, minimum, and range. See Table A.4

**Table A.4** Maximum, Minimum, and Range per Cycle

| Month | Forecast | $\Delta D(t)$ | Sorted $\Delta D(t)$ | Smoothed Forecast | | | |
|---|---|---|---|---|---|---|---|
| Dec-04 | 3,062 | | | | | | |
| **Jan-05** | **7,697** | **4,634** | **4,634** | **7,697** | | | |
| **Feb-05** | **8,721** | **1,024** | **2,361** | **10,058** | | | |
| **Mar-05** | **11,082** | **2,361** | **1,398** | **11,456** | | | |
| **Apr-05** | **7,828** | **(3,254)** | **1,024** | **12,480** | | | |
| **May-05** | **8,388** | **560** | **651** | **13,131** | | | |
| **Jun-05** | **9,038** | **651** | **595** | **13,726** | | | |
| **Jul-05** | **7,762** | **(1,276)** | **560** | **14,286** | | | |
| **Aug-05** | **7,774** | **12** | **12** | **14,298** | | | |
| **Sep-05** | **8,369** | **595** | **(958)** | **13,340** | | | |
| **Oct-05** | **9,768** | **1,398** | **(1,276)** | **12,063** | Period | | |
| **Nov-05** | **8,809** | **(958)** | **(2,630)** | **9,433** | Max | min | range |
| **Dec-05** | **6,179** | **(2,630)** | **(3,254)** | **6,179** | 14,298 | 6,179 | 8,119 |
| Jan-06 | 8,756 | 2,577 | 2,686 | 8,865 | | | |
| Feb-06 | 9,922 | 1,165 | 2,577 | 11,442 | | | |
| Mar-06 | 12,608 | 2,686 | 1,591 | 13,033 | | | |
| Apr-06 | 8,906 | (3,702) | 1,165 | 14,199 | | | |
| May-06 | 9,543 | 637 | 740 | 14,939 | | | |
| Jun-06 | 10,283 | 740 | 677 | 15,616 | | | |
| Jul-06 | 8,831 | (1,452) | 637 | 16,253 | | | |
| Aug-06 | 8,844 | 14 | 14 | 16,266 | | | |
| Sep-06 | 9,521 | 677 | (1,090) | 15,176 | | | |
| Oct-06 | 11,112 | 1,591 | (1,452) | 13,724 | Period | | |
| Nov-06 | 10,022 | (1,090) | (2,993) | 10,732 | Max | min | range |
| Dec-06 | 7,030 | (2,993) | (3,702) | 7,030 | 16,266 | 7,030 | 9,236 |
| **Jan-07** | **9,816** | **2,786** | **3,011** | **10,041** | | | |
| **Feb-07** | **11,122** | **1,306** | **2,786** | **12,827** | | | |
| **Mar-07** | **14,133** | **3,011** | **1,783** | **14,610** | | | |
| **Apr-07** | **9,983** | **(4,150)** | **1,306** | **15,917** | | | |
| **May-07** | **10,697** | **714** | **830** | **16,746** | | | |
| **Jun-07** | **11,527** | **830** | **759** | **17,505** | | | |
| **Jul-07** | **9,899** | **(1,628)** | **714** | **18,219** | | | |
| **Aug-07** | **9,915** | **15** | **15** | **18,234** | | | |
| **Sep-07** | **10,674** | **759** | **(1,222)** | **17,012** | | | |
| **Oct-07** | **12,457** | **1,783** | **(1,628)** | **15,385** | Period | | |
| **Nov-07** | **11,235** | **(1,222)** | **(3,355)** | **12,030** | Max | min | range |
| **Dec-07** | **7,880** | **(3,355)** | **(4,150)** | **7,880** | 18,234 | 7,880 | 10,354 |

| Month | Forecast | $\Delta D(t)$ | Sorted $\Delta D(t)$ | Smoothed Forecast | | | |
|---|---|---|---|---|---|---|---|
| Jan-08 | 10,875 | 2,995 | 3,336 | 11,216 | | | |
| Feb-08 | 12,323 | 1,447 | 2,995 | 14,211 | | | |
| Mar-08 | 15,659 | 3,336 | 1,976 | 16,187 | | | |
| Apr-08 | 11,061 | (4,598) | 1,447 | 17,635 | | | |
| May-08 | 11,852 | 791 | 919 | 18,554 | | | |
| Jun-08 | 12,771 | 919 | 841 | 19,395 | | | |
| Jul-08 | 10,968 | (1,803) | 791 | 20,186 | | | |
| Aug-08 | 10,985 | 17 | 17 | 20,203 | | | |
| Sep-08 | 11,826 | 841 | (1,354) | 18,849 | | | |
| Oct-08 | 13,802 | 1,976 | (1,803) | 17,046 | Period | | |
| Nov-08 | 12,448 | (1,354) | (3,717) | 13,329 | Max | min | range |
| Dec-08 | 8,731 | (3,717) | (4,598) | 8,731 | 20,203 | 8,731 | 11,472 |
| **Jan-09** | **11,935** | **3,204** | **3,661** | **12,392** | | | |
| **Feb-09** | **13,523** | **1,589** | **3,204** | **15,596** | | | |
| **Mar-09** | **17,184** | **3,661** | **2,168** | **17,764** | | | |
| **Apr-09** | **12,139** | **(5,046)** | **1,589** | **19,353** | | | |
| **May-09** | **13,007** | **868** | **1,009** | **20,362** | | | |
| **Jun-09** | **14,015** | **1,009** | **923** | **21,284** | | | |
| **Jul-09** | **12,036** | **(1,979)** | **868** | **22,152** | | | |
| **Aug-09** | **12,055** | **18** | **18** | **22,171** | | | |
| **Sep-09** | **12,978** | **923** | **(1,486)** | **20,685** | | | |
| **Oct-09** | **15,146** | **2,168** | **(1,979)** | **18,706** | Period | | |
| **Nov-09** | **13,660** | **(1,486)** | **(4,079)** | **14,627** | **Max** | **min** | **Range** |
| **Dec-09** | **9,582** | **(4,079)** | **(5,046)** | **9,582** | 22,171 | 9,582 | 12,589 |

Step 7: For the rearranged forecast, calculate the growth intercept, slope, and average. With that information calculate the seasonal index $S_i$ as shown in Table A.5.

**Table A.5** Calculation of Demand Variation Parameters

| | Max | min | range |
|---|---|---|---|
| 2005 | 14,298 | 6,179 | 8,119 |
| 2006 | 16,266 | 7,030 | 9,236 |
| 2007 | 18,234 | 7,880 | 10,354 |
| | Max | min | range |
| 2008 | 20,203 | 8,731 | 11,472 |
| 2009 | 22,171 | 9,582 | 12,589 |
| | | | |
| Average Maximum | 18,234 | Average Smoothed forecast | 14,637 |
| Average minimum | 7,880 | $S_i$ | 0.7073 |
| Average Range | 10,354 | Intercept | 10,872 |
| | | Trend | 126 |

Therefore:

| | | |
|---|---|---|
| $a_i$ = | 126 request/ period | Slope of demand curve for service *i*. |
| $b_i$ = | 10,872 requests | Intercept of demand curve for service *i*. Trend minimum demand expected for the planning period for service *i* |
| $T$ = | 60 periods | Number of periods (months) in the planning horizon |
| $S_i$ = | 0.7073 | Average range of the cyclical index. |
| $\tau_i$ = | 12 periods | Average length of seasonal cycles. |

Figure A.2 shows the result of rearranging the forecast. At the strategic level, it is important to quantify the total demand variation to determine the total capacity variation and compare the different service suppliers under these capacity requirements.

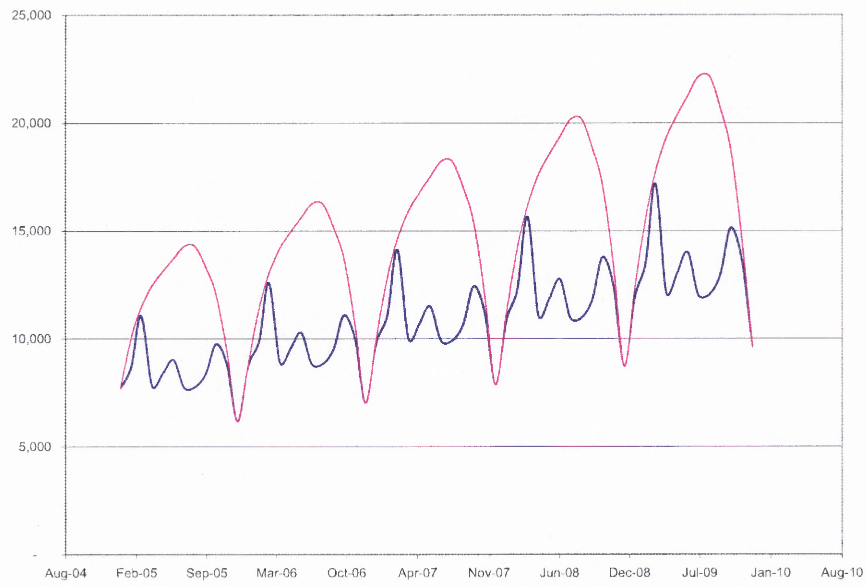



**Figure A.2** Example of smoothed forecast.

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