CAPACITY PLANNING AND RANGE SETTING IN QUANTITY FLEXIBILITY CONTRACTS AS A MANUFACTURER

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ABSTRACT

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Quantity Flexibility contract is an arrangement where parties agree upon a scheme of forming ranges on volumes for their future transactions. The contract is based on setting upper and lower limits on replenishment orders as simple multiples of point estimates updated, published and committed by the buyers. We introduce a manufacturer with a limited capacity; also capable of subcontracting, for deliveries with a known lead time. He offers a Quantity Flexibility (QF) contract to a buyer while he has an active contract with another buyer serving a market with known demand forecast distributions. Using two-stage stochastic programming we study the effects of flexibility multiples and the environmental factors on the buyers' incentives and manufacturer's capacity planning. Finally, the motivations of the Supply Chain actors to behave independently or to be involved into the integrated

supply chain where information asymmetry is removed are investigated. Our experiments underline the critical roles played by the forecast accuracy and information sharing.

Keywords: Supply Chain Management, Supply Contracts, Quantity Flexibility, Capacity Planning, Stochastic Programming, Benders Decomposition.

ÖZ

MİKTAR ESNEKLİĞİ KONTRATLARINDA İMALATÇI AÇISINDAN KAPASİTE PLANLAMA VE ARALIK BELİRLEME

Pesen, Şafak

Yüksek Lisans, Endüstri Mühendisliği Bölümü

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Miktar Esnekliği kontratı, tarafların gelecek siparişlerinin miktarları için aralık belirleme metodunda anlaşma sağladığı bir düzenlemedir. Bu kontrat tipi, müşterinin değiştirdiği, ilan ettiği ve taahhüt ettiği nokta tahminlerinin basit katları olarak alt ve üst sınırları düzenlenen sipariş miktarlarına dayanmaktadır. Kapasitesi sınırlı, aynı zamanda sabit tedarik zamanında fason üretimi teslim alabilen bir imalatçı ele alınmıştır. İmalatçı, talep tahmini dağılımları bilinen bir pazara mal satan bir müşteriyle miktar esnekliği (ME) kontratı yapmışken, başka bir müşteriye de ME kontratı önerir. İki aşamalı rassal programlama kullanılarak esneklik çarpanlarının ve çevresel etkilerin müşterilerin davranışlarına ve imalatçı firmanın kapasite planlamasına etkileri incelenmiştir. Son olarak, tedarik zinciri aktörlerinin tek başlarına hareket etme ya da tüm kararların paylaşıldığı entegre tedarik zincirine

dahil olma tutumları belirlenmiştir. Deneylerimiz, tahmin doğruluğu ve bilgi paylaşımının oynadığı kritik rolleri vurgulamaktadır.

Anahtar Kelimeler: Tedarik Zinciri Yönetimi, Tedarik Kontratları, Miktar Esnekliği, Kapasite Planlama, Rassal Programlama, Benders Ayrışması.

To my Family and Esteban

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CHAPTER I

INTRODUCTION

A Supply Chain (SC) is a network of organizations that are involved in the different processes and activities that produce value in the form of products and services in the hands of ultimate consumer. Supply Chain Management (SCM) deals with the management of material, information and financial flows in this network consisting of vendors, manufacturers, distributors and customers. That is, supply chain consists of multiple decision makers with possibly conflicting objectives linked by a flow of goods, information and funds.

Operations Management area is split into three main application contexts, namely customer management, production management, and product development. Customer management concerns the activities related to identify the key target market and implement programs with key customers. Production management includes different processes such as procurement, forecasting, order fulfillment, quality control and planning, and logistics. Product development, when dealt with according to SCM, involves strategies such as the design for SCM, and the design for localization. When production management area is taken into consideration, broad types of SCM problems in this specific context can be classified as SC configuration and SC coordination.

Configuration mainly involves problems at a strategic level dealing with the design of the supply chain network, in particular supply, production and distribution networks. Relevant decisions in the design of the supply network concern the make or buy problem, the supply strategy, the sourcing policies, and the manufacturer selection process. To sum up, solving a configuration problem means to determine the nodes of SC and related linkages as well as identify the actors that operate them.

Coordination problems concern the management of the supply chain network prevalently under tactical and operating perspectives. Hence, the coordination problems in a SC are quite complex that they arise from the need of integrating operational decisions, which are generally made by several different decision makers. Such decisions, which can concern a single function or different functions, and involve more than one organization, should be coherently guided in order to increase the total SC performance, that is, channel coordination. The channel coordination is achieved in two broad categories, which are centralized and decentralized decision making processes.

A centralized decision making process is associated with a unique decision maker in the SC who should possess all the information on the whole SC that is relevant with making decision as well as with the contractual power to have such decisions to be implemented. When the decision making process is decentralized, several decision makers exists in the SC who generally possess information on only a part of the SC, pursue different objectives, possibly conflicting among each other. Hence, in the selection of a SCM model appropriate to a given problem, beside the quite obvious importance related to whether the coordination is intra functional, inter-functional, or inter organizational, a key issue is to realize whether the decision making process will occur in a centralized or decentralized fashion.

Consequently, coordination has become an important issue in the optimization of the performance of the supply chain. Some contractual arrangements are used to improve the efficiency of the supply chain. These arrangements include the reallocation of decision rights, rules for sharing the costs of inventory and stock out, and policies governing pricing either to the end customer or between supply chain partners. In other words, a contractual arrangement, i.e. supply chain contract, is a coordination mechanism that provides incentives to all of its members, so that the decentralized supply chain behaves nearly or exactly the same as the integrated one.

The contract analysis offer guidance in negotiating the terms of the relationship between the buyer and the manufacturer, i.e., supply chain actors. Most of the published works in the field treat the terms of contractual relationship as decision variables, such as price, lead time, and bounds on order size.

Contracts are designed to motivate the parties to pursue certain contract structures. Firstly, the buyer and manufacturer share the risks arising from various sources of uncertainty. (e.g., market demand, delivery time, product quality, etc.). Minimum purchase agreements or penalties for returns are often included in contracts to protect the manufacturer against this risk happening. Secondly, by channel coordination, the causes of the inefficiency of the supply chain can be identified and the structure of the relationship can be modified. Also, by explaining shared allowances as well as specifying penalties for non-cooperative behavior, long term partnerships can be facilitated. Finally, like lead time, on time delivery rates and conformance rates, the terms of a relationship are made explicitly in order to make the expectations of each party concrete.

The set of parameters over which supply contracts are observed can be classified in some categories, which are horizon length, pricing, periodicity of ordering, quantity commitment, time and quantity flexibility, delivery commitment, quality, and information sharing.

The main types of contracts in some of the categories declared above can be stated as follows;

The total minimum quantity commitment: The buyer guarantees that his cumulative orders for all periods in the contract horizon will exceed a specified minimum quantity. In return, the manufacturer offers price discounts. Backup agreements are in this category.

The total minimum quantity commitment with flexibility: The manufacturer imposes restrictions on the total purchases at the discounted price. Any quantity ordered above the restriction is available at a higher price.

The periodical stationary commitment: The buyer is required to purchase a fixed amount in each period. Discounts are given based on the level of minimum commitment. Additional units can be purchased at an extra cost. Often, the manufacturer imposes restrictions on the total purchases at the discounted price. Any quantity ordered above the restriction is available at a higher price.

The periodical commitment with order bands: The buyer is required to restrict the order quantities to be within constant specified lower and upper limits. The unit price depends on the band-width and increases with the band-width.

The periodical commitment with rolling horizon flexibility: At the beginning of the horizon, the buyer commits to purchase given quantities every period. The buyer has a limited flexibility to purchase quantities different from the original commitments. The buyer is allowed to update the previously made commitments, within a given limitation. The unit price decreases with the allowed flexibility. Quantity flexibility contracts are included in this type of contracts.

The periodical commitment with options: At the beginning of the horizon, the buyer commits to purchase given quantities every period. The buyer has a limited flexibility to purchase options at unit option price from the manufacturer that allows him to buy additional units, by paying an exercise price. So, options permit the buyer to adjust orders quantities to the observed demands. Under some assumptions, these contracts with options encompass backup agreements contracts, periodical commitment contracts with flexibility (quantity flexibility contracts) and pay-to-delay arrangements.

Delivery commitment: The manufacturer makes a commitment for the material delivery process. A commitment on the lead time would specify delay in delivery of the material. Thus, there a chance of adjusting lead time via the contractual agreement. Service level agreements on lead time for the entire order or on fraction of the order are common.

Quality commitment: The manufacturer and the buyer have a relationship premised on the quality of the delivered product, in terms of defects rates, stipulation of penalties for defective products. The quality is treated as a product attribute which has a positive effect on both sales volume and production cost.

Information sharing: In the contractual agreement, the information flow between a buyer and a manufacturer is characterized. The contract outlines what types of information will be shared between the buyer and manufacturer.

Thus far, the categories described (Delft, Vial 2001) are mainly concerned with the timing and quantity of material flows and the associated financial transfers. The specific contracts, namely Quantity Flexibility Contracts, Backup Agreements, Option Contract, and Pay-to-Delay Capacity Reservation Contracts will be particularly illustrated in the following.

Quantity Flexibility contracts is a way to encourage the buyer to forecast and plan more deliberately and honestly, on the other hand, the manufacturer might need to provide a price break to give the buyer an incentive to participate. In such arrangements, the buyer commits to purchase no less than a certain percentage ω below the forecast and the manufacturer guarantees to deliver up to a certain percentage α above the forecast. After observing the demand for a short period, the buyer can decide to order any quantity between $(1-\omega)q$ and $(1+\alpha)q$ at the wholesale price c, where q is the initial order placed by the buyer. The QF relationship between the manufacturer and the buyer can be described by the following parameters $\{c, (\alpha, \omega)\}$, where c is the transfer price.

Backup agreements are contracts between a catalog company and manufacturers, which are similar to quantity flexibility contracts. Under a backup agreement, the catalog company commits to purchase y units before the selling season, and the manufacturer holds back a fraction ρ of the commitment (ρy) and delivers the remaining units ($(1-\rho)y$) before the start of the fashion season. After observing demand, the catalog company can order up to this backup quantity at the same purchase price and receive quick delivery, but will pay a penalty cost b for any backup units that it does not buy. Backup agreements intend to help catalog company reduce the impact of uncertainty about demand.

In Option contract, before the beginning of the horizon the buyer makes three decisions. He places firm orders for goods to be delivered at the beginning of periods one and two at a regular price, ω. In addition, at the beginning of the selling season, he purchases options (n) at an option price, ω_0, from the manufacturer. After observing demand in period one, he has the opportunity to order (exercise) additional units of the product (up to the number of options purchased) at an exercise price, ω_e, before the start of period two.

Under pay-to-delay capacity reservation agreements, a buyer makes a total reservation z of which he is obligated to purchase at least $y<z$ units (called take-or-pay). He pays a unit of cost c_f for the take-or-pay capacity and a unit option cost of c_o for z-y units. Additional units up to a maximum z-y can be bought at an extra unit of cost of c_e. That is, allocation and reservation for capacity is offered by a manufacturer in return for a fixed up-front payment. The buyer could place orders at a later date and use the up-front payment towards actual procurement costs. A large portion of the allocation is usually take-or-pay capacity, for which the manufacturer will have to pay the production cost even if he does not need the products.

Among the SCM models that adopt a decentralized decision making process, we analyze the supply chain contracts, which include the quantity flexibility, the backup agreements, options and pay-to-delay reservations. From these contracts, aiming at achieving channel coordination and risk sharing among the SC actors, the quantity flexibility contract is selected to study. Quantity flexibility models are coordination mechanisms that divide the costs of demand uncertainty among the SC actors. In this particular arrangement, the buyer, who is facing with the uncertain demand, tries to forecast his own replenishment amounts to the manufacturer. Since the informed amounts are only forecasts, the manufacturer, deals with, this time, uncertain buyer's orders. The buyer and manufacturer have their own rolling ranges, over which quantities are restricted. Further, in the future according to the flexibilities introduced, forecasts are given the chance of adjustment within the specified ranges. However, these ranges are neither independent of the parties' decisions nor are separated from one another through time. Therefore, by quantity flexibility models, the costly effects of uncertainty on the decision making processes of the SC actors, are tried to be reduced by giving ranges which provide the modifications of the declared forecasts in rolling horizon basis.

A key component of decision making under uncertainty is the representation of the stochastic parameters. Two distinct ways of representing uncertainty exist. The scenario-based approach attempts to represent a random parameter by forecasting all its possible future outcomes. The main drawback of this technique is that the number of scenarios increases exponentially with the number of uncertain parameters, leading to an exponential increase in the problem size. To avoid this difficulty, continuous probability distributions for the random parameters are frequently used. At the expense of introducing nonlinearities into the problem through multivariate integration over the continuous probability space, a considerable decrease in the size of the problem is usually achieved. This approach has been widely invoked in the literature as it captures the essential features of demand uncertainty and is convenient to use.

One of the most widely used techniques for decision making under uncertainty is two-stage stochastic programming. In this technique, the decision variables of the problem are partitioned in two sets. The first-stage variables, also known as design variables, correspond to those decisions that need to be made prior to resolution of uncertainty ("here and now" decisions). For instance, due to the significant lead times associated with the activities such as raw material consumption, capacity utilization, budget allocation in stock management and final product production, decisions covering these tasks can be modeled as "here and now" decisions. Subsequently, based on these decisions and the realization of the random events, the second-stage or control decisions are made subject to the restrictions of the second-stage recourse problem ("wait and see" decisions). For example, post-production activities such as inventory management, flow of materials throughout the production system and supply of finished good product to the customer, can be fine-tuned in a "wait and see" setting after the realization of the random demand. The presence of uncertainty is translated into the stochastic nature of the costs associated with the second-stage decisions. Then, the overall objective function consists of the sum of the first-stage decision costs and the expected second-stage recourse costs in terms of the first stage (design) variables. Hence, the overall problem can be expressed in two-stage stochastic programming model where there is an interaction between the first stage (outer) and second stage (inner) problems.

Stochastic programming with recourse models are ideally suited for analyzing resource acquisition planning problems from two perspectives. They combine deterministic mathematical programming models for allocation resources optimally with decision analysis models that provide hedging strategies in an uncertain environment.

The main challenge associated with solving two-stage stochastic problems is the evaluation of the expectation of the inner recourse problem. For the scenario-based representation of uncertainty, this can be achieved by explicitly associating a second-stage variable with each scenario and solving the large-scale formulation by efficient solution techniques such as Dantzig-Wolfe decomposition and Benders decomposition. For continuous probability distributions, this challenge has been primarily resolved through discretization of the probability space for approximating the multivariate probability integrals. The two most commonly used discretization strategies are Monte Carlo sampling and Gaussian quadrature.

CHAPTER II

LITERATURE REVIEW

In Quantity Flexibility contract, the buyer is pushed to forecast and plan more deliberately and honestly, whereas, the manufacturer might need to provide a price break to give the buyer an incentive to participate. In this arrangement, the buyer commits to purchase no less than a certain percentage ω below the forecast and the manufacturer guarantees to deliver up to a certain percentage α above the forecast. After observing the demand for a short period, the buyer can decide to order any quantity between $(1- \omega)q$ and $(1+ \alpha)q$ at the wholesale price c, where q is the initial order placed by the buyer. The QF relationship between the manufacturer and the buyer can be described by the following parameters $\{c, (\alpha, \omega)\}$, where c is the transfer price.

Tsay and Lovejoy (1999) extend the QF contract in a multi-echelon SC with a rolling production planning horizon. They study the impact of system flexibility on inventory characteristics and the patterns by which forecast and order variability spread along the supply chain. They also work on the design of QF contracts, i.e. providing insights as to where to position flexibility for the greatest benefit, and how much to pay for it, in particular by analyzing the buyer's "willingness to pay" for flexibility. Their analysis provides heuristics based on open loop feedback control logic indicating how the buyer should construct his replenishment amounts in light of the market demand and the flexibility parameters, as well as how the manufacturer should behave (submission of orders, forecasting to its own upstream manufacturer) in order to fulfill its contractual commitment to support the buyer's order sequence. In their extensive numerical studies, they evaluate the impact of demand variance, flexibility parameters on the inventory costs, fill-rate, and variability in the other and forecast processes. They conclude that the presence of flexibility can diminish the transmission of the variability up to the chain, and suggest that inventory management can be viewed as the management of process flexibilities. Different from Tsay and Lovejoy, we include capacity restriction for the replenishments. We also have the option of subcontracting in order to increase the capacity specified for the amount to be replenished.

Tsay (1999) considers a decentralized supply relationship in which the buyer's advance forecast need not imply complete commitment to its subsequent purchase quantity in response to improved demand information. Rather than assuming a passive manufacturer who simply accommodates the buyer's actions, he develops a behavioral model of each party's local incentives. By examining the incentives on each side of the relationship, he has found that inefficiency will result in the absence of additional structure. He identified particular forms of behavior, such as over forecasting, or simply making decisions based on a local rather than global perspective. He has shown that these problems can be at least partially remedied by the QF contract, where the buyer commits to a minimum purchase and the manufacturer guarantees a maximum coverage. He states that there is a trade off between flexibility and unit price, with the buyer willingly paying more for increased flexibility. He has demonstrated that incentives and information are distinct causes of inefficiency. However, his results demonstrate efficiency only under shared beliefs. The issue of coordination under information asymmetry remains unresolved.

Bassok and Anupindi (1997), analyze a supply contract for a single product that specifies the cumulative orders placed by a buyer, over a finite horizon, be at least as large as a given quantity. They assume the demand for the product is uncertain and the buyer makes a commitment a priori to purchase a minimum quantity periodically. They derive structure of the optimal purchase policy for the buyer for a given total minimum quantity commitment and a discount price. They show that the policy is characterized in terms of the order-up-to-levels of the finite horizon version of the standard newsboy problem with discounted purchase price and the order-up-to-level of a single period standard newsboy problem with no commitment to the manufacturer but with zero purchase cost and discounted price. Their main contributions are that they introduce the notion of a minimum commitment over the horizon in stochastic environment and they show that this policy can be used to evaluate and compare different contracts, determine whether a contract is profitable, and identify the best contract. Using computational study, they demonstrate the effect of commitments, coefficient of variation of demand, percentage discount and penalty costs on savings.

Li and Kouvelis (1999) analyze different types of SC contracts, which are based on quantity and time flexibility. In time inflexible contracts, the buyer is required to specify at time 0 how many units he intends to purchase from the manufacturer, but the contract does not require to specify when those units will be purchased. After the buyer signed the time-flexible contract, he can observe the price movement and decide dynamically when to trigger a buy. Besides time flexibility, in

SC contract with quantity flexibility, the buyer signs a contract of Q units with a manufacturer and the contract has α x 100% quantity flexibility, where α is between zero and one. The manufacturer does not require the buyer to purchase all Q units from him later. The buyer can purchase a total of x units from the manufacturer where $(1-\alpha)Q \le x \le Q$. The authors develop a model where demand is deterministic and price is uncertain. Moreover, they study the buyer's decision when to purchase and how many units to order in each purchase such that the expected net present value of the purchase cost plus inventory holding cost is minimized. They discussed optimal purchasing strategies for both time-flexible and time-inflexible contracts with risk-sharing features and illustrate how time flexibility, quantity flexibility, manufacturer selection, and risk sharing, when carefully exercised, can effectively reduce the sourcing cost in environments of price uncertainty.

Bassok, Srinivasan, Bixby and Wiesel (1997) study the supply contract where at the beginning of the contract, the buyer makes purchasing commitments to the manufacturer for each period. The buyer may have some flexibility to purchase quantities that actually deviate from the original commitments. Moreover, as time passes and more information about the actual demand is collected, the buyer may update the previous commitments, in a way that is agreed upon. They develop a heuristic that determines nearly optimal commitments and purchasing quantities. The heuristic is used to evaluate the worth of flexibility to adjust the commitments and orders according to the changing conditions of the marketplace. It does capture the dynamic nature of the problem by maximizing the probability of reaching the base-stock levels that are optimal for the news-vendor problem and provides a mechanism to determine the static commitments.

Anupindi and Bassok (1998b) address two main streams of research; analysis and design of contracts. They focus on the issue of quantity commitments and flexibility. They motivate and present several types of contracts structured using quantity commitments and flexibility. The contracts; total minimum quantity commitment, total minimum dollar volume commitment, rolling horizon flexibility and periodical commitments with options are analyzed analytically. Their rolling horizon flexibility contract analyzed for a multi-echelon system is called quantity flexibility contract by Tsay and Lovejoy (1999). In RHF, at the beginning of the horizon, the buyer commits to purchase a certain quantity every period. The buyer has limited flexibility to purchase quantities that are somewhat different than the original commitments, and is also allowed to update the previously made commitments within a given range of $(1-\alpha_d)Q_{t-1}$ and $(1+\alpha^u)Q_{t-1}$, where α_d and α^u are downward and upward flexibility parameters, respectively. They describe that the quantity commitments provide the manufacturer with reliable information with respect to the buyer's overall demand and specific future orders and reduce the uncertainty passed onto the manufacturer and share the risks due to uncertainty between the two parties. In the paper, they concentrate on incentive contracts and assume symmetric information between the two parties and suggest commitments together with options as a mechanism to achieve coordination of the channel.

Bassok and Anupindi (1998) address Rolling Horizon Flexibility (RHF) contracts. Under such a contract, a buyer has to commit orders for requirements of components in each period, at the beginning of the horizon. Usually, the manufacturer provides flexibility to adjust the current order and future commitments in a limited way and in a rolling horizon fashion. They present a general model to study RHF contracts and propose two measurements for the order process that capture the variability in the order process and advance information shared between the manufacturer and buyer through commitments. Also, they propose several heuristics and derive a lower bound to the optimal solution of RHF contract. Effectiveness of the heuristics for both stationary and non-stationary demands is numerically demonstrated. Their work is similar to Tsay and Lovejoy (1999) in many respects, but focuses on a more in-depth analysis of a single stage system which faces non-stationary demand. They show that often “unlimited” flexibility offered by a newsvendor model is unnecessary; larger flexibilities allow a buyer to offer higher service levels, the variability in the order process is lower than the variability in the demand process, the mean absolute deviation of the commitment from the actual order decreases as we get closer to the period in which orders are placed.

Milner and Rosenblatt (1997) analyze a setting where the buyer places orders for two periods, and may then adjust the second order after observing demand in first period. Their study differs from the contract in Bassok and Aupindi (1997) in that there is per unit penalty for any adjustments. They describe the optimal behavior of the buyer, both in the initial orders and subsequent adjustment. The optimal adjustment is characterized by a range [L, U], where the endpoints are simple functions of the cost parameters and the demand distributions. If the pre-adjustment inventory position on entering the second period falls in this interval, no adjustment should be made. Otherwise, to get to the closest boundary of the interval an adjustment is carried out. Closed forms are not available for the optimal initial orders, but some structural properties are presented. Finally, parameter combinations, which characterize the buyer’s preference for either the flexible contract, a nonflexible contract, or no contract at all, are derived. The manufacturer's preferences are not considered.

Chen and Krass (2001) address a buyer-manufacturer arrangement of particular importance namely total order quantity commitment (TOQC). They consider the procurement and inventory control problem in which the buyer can combine the two different purchasing strategies; purchasing on a commitment basis and on an as-ordered basis. On the commitment basis, the buyer ensures that her cumulative-order quantities during the contract period should be no less than the committed amount, which she has agreed at the beginning of the contract period. After the quantity specified in the commitment has been purchased, any additional units can be purchased on the as-ordered basis. To encourage the buyer to commit to greater quantities, the manufacturer usually provides a quantity discount pricing schedule according to which, the greater the commitment, the lower the per unit price. In addition, the buyer still reserves the flexibility to place delivery orders depending upon her inventory replenishment policy. That is, the buyer does not have to set a predetermined delivery schedule with the manufacturer. The optimal inventory replenishment policy is shown to be dual order-up-to levels under a given TOQC, and the optimal TOQC is also demonstrated to be mathematically straightforward to obtain. They extend the model of Bassok and Anupindi (1997) to a more general setting, which account for, non-stationary demand distributions, different per unit prices for purchases on commitment basis and as-ordered basis.

Plambeck and Taylor (2002) consider a setting in which two buyers invest in innovation (product development, marketing) and obtain supply from a single manufacturer through quantity flexibility contracts, which specify the minimum quantity the manufacturer must supply and the minimum quantity the buyer must purchase. They show that the potential for renegotiation of the supply contracts has important implications for the way firms make investments in innovation and capacity, the way capacity is allocated, and the resulting profits of SC actors. Conducting cooperative game theory, they provide the conditions under which the potential for renegotiation motivates or slows down the buyer's incentive to invest in innovation. They demonstrate that, when the parameters of the quantity flexibility contracts are chosen optimally, renegotiation always increases the expected total system profit. Although renegotiation involves costly delay, managerial effort, and legal fees, they have also assumed that renegotiation is costless.

Under a backup agreement similar to quantity flexibility contract, the catalog company commits to purchase y units before the selling season, and the manufacturer holds back a fraction ρ of the commitment (ρy) and delivers the remaining units ((1-ρ)y) before the start of the fashion season. After the demand is observed, the catalog company can order up to this backup quantity at the same purchase price and receive quick delivery, but will pay a penalty cost b for any backup units that it does not buy.

Eppen and Iyer (1997) develop a stochastic programming model of backup agreements. In particular, they study the impact of contract parameters (b, ρ) on the expected catalog company's profit. An increase in the value of b is accompanied by a reduced advantage of using a backup agreement, whereas oppose occurs for an increase of ρ. The latter effect is reduced by an increase of b. They also develop an expression to measure the impact of backup agreements on the manufacturer's profit and show that for certain values of (b, ρ) both the catalog company and manufacturer profits improve. They conclude that backup is an important practice in the merchandising of fashion goods that can benefit both the buyer and the manufacturer, and adjusting the order commitment in response to the offered ρ can have a significant impact on expected profit.

In Option contract, the buyer makes a firm order, q, at the beginning of the season at a wholesale price, ω. In addition, he purchases options (n) at an option price, ω_0. After the demand of first period is observed, the buyer may choose to order (exercise) additional units of the product (up to the number of options purchased) at an exercise price, ω_e, before the start of period two.

Barnes-Schuster, Bassok and Anupindi (2000) investigate the role of options in a buyer-manufacturer system. They illustrate how options provide flexibility to a buyer to respond to market changes in the second period and demonstrate the benefits of options in improving channel performance. They show that backup agreements, two-period quantity flexibility contracts, and pay-to-delay arrangements are special cases of their general model. They show that if the exercise price is piecewise linear, channel coordination can be achieved unconditionally. The manufacturer can then implement the channel coordination solution using either a simple or bundled all unit quantity discount schemes. For a Stackelberg game model of the manufacturer-buyer system in which the manufacturer is restricted to linear pricing schemes, they numerically evaluate the value of options and coordination as a function of demand correlation and the service level offered, providing several managerial insights. Finally, they have illustrated how return policies, in conjunction with linear prices, can be used to coordinate the channel and allow the manufacturer to extract the channel profits.

Spinler, Huchzermeir and Kleindorfer (2002) consider contracts that provide options as opposed to a fixed contract on the manufacturer's capacity. Extending the theory of real options, they propose a game-theoretic framework to value options on capacity to produce non-storable goods or dated services, such as electricity or transportation service. They incorporate all relevant exogenous risk factors, i.e., demand, price and cost risk, into a game theoretic market model for the valuation of options on capacity. They also derive analytical expressions for the buyer's optimal reservation quantity and the seller's optimal options tariff, making explicit the risk-sharing benefits of options contracts accruing to both buyer and seller. They have demonstrated gains in economic efficiency for the options plus spot market, which render risk-sharing and planning instruments via options particularly attractive. Finally, they showed that the gains increase with higher risk of finding a last-minute buyer and with increasing cost gap between long term and short term allocation.

Under pay-to-delay capacity reservation agreements, a buyer makes a total reservation z of which he is obligated to purchase at least $y<z$ units (called take-or-pay). He pays a unit of cost for the take-or-pay capacity. Additional units up to a maximum z-y can be bought at an extra unit of cost. The buyer could place orders at a later date and use the up-front payment towards actual procurement costs.

Brown and Lee (2000) consider a two-stage "flexible" supply contracts for advanced reservation of capacity or advanced procurement of supply. With a contract of this type, an initial quantity decision is made with limited demand information. After learning new information about the demand, a final decision can be made that is constrained by the initial decision. They consider the scenario where a large supplier offers a standard contract to a small manufacturer. They focus on a general options-futures contract that allows for initial reservation of capacity as a less expensive, non-refundable firm commitment, i.e., futures or as a more expensive but flexible option, i.e., options. The demand signal is defined as to be the information that arrives after the initial decision point and before the final decision point. They characterize the impact of demand signal quality on optimal quantity decisions. They show that for the options-futures contract, the number of options increases and the number of futures decreases with increasing demand signal quality. Finally, they find that for the backup and quantity flexibility contracts, the initial order quantity does not behave monotonically with demand signal quality. They display the bounds $(1-\omega)q$ and $(1+\alpha)q$ of QF contracts as number of futures and total reservation, respectively.

Erkoc and Wu (2002) study capacity reservation contracts in high-tech manufacturing, where the manufacturer shares the risk of capacity expansion with the buyer. They focus on short-life-cycle; make to order products under stochastic demand. The manufacturer and the buyer are defined as partners who enter a "design-win" agreement to develop the product, and who share demand information. The manufacturer would expand her capacity in any case, but reservation may encourage her to expand more aggressively. To reserve capacity, the buyer pays a fee upfront while the fee is deductible from the order payment. They show that as the buyer's revenue margin decreases, the manufacturer faces a sequence of three profit scenarios for the specification of the optimal reservation fee, with a decreasing desirability. They examine the effects of market size and demand variability to the contract conditions, and show that it is demand variability that affects the reservation fee. They propose two channel coordination contracts, which are capacity reservation with partially deductible payments and coordination via cost sharing contracts. Finally, they discuss additional cases where the manufacturer has the option not to comply with the contract, and when the buyer's market size is only partially known.

Huang, Sethi and Yan (2002) study a buyer's problem involving a purchase contract with a demand forecast update. Because of the presence of a lead time, the buyer makes an initial purchase decision with a preliminary forecast. The purchase contract provides the buyer a chance to adjust an initial commitment based on an updated demand forecast obtained at a later stage. An adjustment, if any, incurs a fixed as well as a variable cost. They formulate the buyer's problem as a two-stage dynamic programming problem, where the decisions are the initial order quantity and the reaction plan which specifies how to adjust the initial order in view of the improved demand information obtained at stage 2. They obtain the critical value of the fixed contract exercise cost, below which the buyer would sign the contract. Their model could be considered as a two-stage extension of the classical newsvendor problem to allow for a contract, a fixed cost, a forecast update, and a possibility of the initial order adjustment, while, at the same time, preserving the explicitness of the solution. They prove that the optimal cost function is monotone with respect to the contract exercise cost. In addition, they demonstrate the asymptotic property of the cost function.

Quantity flexibility models are coordination mechanisms that divide the costs of demand uncertainty among the SC actors. That is, QF contract involves decision making under uncertainty. In quantity flexibility contracts, decisions are of the form; first predict to prescribe, and then see to specify. First, the buyer predicts the demand for the periods in the planning horizon. Then they are prescribed as forecasted delivery ranges from the manufacturer. After the demand is realized, the buyer experiences, i.e., sees the demand of the first period; he specifies the actual release quantity for the first period to the manufacturer to be replenished. He also has the option to adjust the estimated replenishment schedule within the specified bounds constructed according to the QF parameters on a rolling horizon basis. Then one period passed, and the newly predicted replenishment ranges are prescribed as forecasted delivery ranges from the manufacturer. Consequently, the problem can be seen as two-stage stochastic problem and can be separated in two parts. The former, that is first stage, consists of the estimated replenishment schedule to be transferred to the manufacturer, which is prior to realization of uncertain demand, and the latter, that is, second stage includes the buyer's actual replenishment schedule after the demand appears.

Birge (1997) describes the basic methodology for the stochastic programming models. He explores recent advances in computational capabilities for stochastic programs and the structure of problems that enables these procedures. After describing various solution techniques and their computational implementations, he provides some insight into the range of possible applications of the methods through a set of examples from actual practice such as finance, manufacturing, telecommunication and transportation. The paper's emphasis is on computational methods with results in practically sized, large-scale problems. He reviewed methods that achieve improved solutions for stochastic models over simplified deterministic models.

Delft and Vial (2001) propose a stochastic programming approach for quantitative analysis of supply contracts with options, involving flexibility between a buyer and a manufacturer, in a supply chain framework. Specifically, they consider the case of multi-period contracts in the face of correlated demands and briefly reviewed the main types of the contracts in the literature. To design such contracts, one has to estimate the savings or costs induced for parties, as well as the optimal orders and commitments. They show how to model the stochastic process of the demand and the decision problem for both parties using the algebraic modeling language AMPL. They compute the optimal strategy for the buyer and manufacturer separately. They then compare the individual performance with the global optimum of a centralized policy in a vertical integrated framework. Finally, they compute the economic performance of these contracts, giving evidence that the methodology allows to gain insight into realistic problems.

Gupta and Maranas (2000) propose a two-stage stochastic programming approach for incorporating uncertainty in multisite midterm supply chain planning problems. In the decision making framework, the production decisions are made "here and now" prior to the resolution of uncertainty, while the supply chain decisions are postponed in a "wait and see" mode. The challenge associated with the expectation evaluation of the inner optimization problem is resolved by obtaining its closed form solution using linear programming duality. Under the normal distribution assumption for the stochastic product demands, the evaluation of the expected second stage costs is achieved by analytical integration resulting in an equivalent convex mixed integer nonlinear problem. Computational requirements for the proposed methodology are shown to be much smaller than those for Monte Carlo sampling. In addition, the cost savings achieved by modeling uncertainty at the planing stage are quantified on the basis of a rolling horizon simulation study.

Gupta, Maranas and McDonald (2000) utilize the framework of midterm, multisite supply chain planning under demand uncertainty to safeguard inventory reduction at the production sites and excessive shortage at the customer. A chance constraint programming approach in conjunction with a two-stage stochastic programming methodology is utilized for capturing the tradeoff between customer demand satisfaction and production costs. In the proposed model, the production decisions are made before demand realization while the supply chain decisions are delayed until the realization of demand. The challenge associated with obtaining the second stage recourse function is resolved by first obtaining a closed form solution of the inner optimization problem using linear programming duality followed by expectation evaluation by analytical integration. Furthermore, analytical expressions for the mean and standard deviation of the inventory are derived and used for setting the appropriate customer demand satisfaction levels in the supply chain. Finally, they show that significant improvement in guaranteed service levels can be obtained for a small increase in the total cost.

Chen, Li and Tirupati (2002) consider the role of product mix flexibility, defined as the ability to produce a variety of products, in an environment characterized by multiple products, uncertainty in product life cycles and dynamic demands. Using a scenario-based approach for capturing the evolution of demand, they develop a stochastic programming model for strategic decisions related to long term technology and capacity planning. The model captures stochastic and dynamic demand, technology mix between dedicated and flexible technologies, economies of scope and economies of scale. Since the resulting stochastic program is quite large and not easy to solve with standard packages, they develop a solution procedure to facilitate implementation the approach. They first demonstrate their algorithm, using augmented Lagrangian method. However, since augmented Lagrangian function is not separable although its feasible region is separable, they propose to use restricted simplical decomposition method which is designed to solve convex programming problems with linear constraints more efficiently than simplical decomposition. By the utilization of this method, they provide optimal solutions for moderate sized nonlinear problems by solving a series of linear problems with linear costs in reasonable time.

Liu and Sahinidis (1996) develop a two-stage stochastic programming approach for process planning under uncertainty. The paper considers the process planing problem with some or all of the parameters that determine the economics of the production plan being random. They first address the case in which forecasts for prices, demands, and availability come in a finite number of possible scenarios, each of which has an associated probability. They take a two-stage approach to this problem. In the first stage, they assume that, due to lead times and contractual requirements for plant construction, capital investment decisions must be made here-and-now. These capacity expansion decisions must be optimal in a probabilistic sense. As the realization of the random parameters is unknown at the time of planning, all different possible scenarios must be anticipated. Subsequently, outcomes of the random variables will be revealed, and, for each second-stage scenario, an optimal operating plan will be selected. Then, they devise a decomposition algorithm for the solution of the stochastic model. The case of continuous random variable is handled through the same algorithmic framework without requiring any a priori discretization of their probability space. Finally a method is proposed for comparing stochastic and fuzzy programming approaches and they state that in the absence of probability distributions, the comparison favors stochastic programming.

Schweitzer (1994) deals with two-stage and multi-stage stochastic programming, with focusing on stochastic quadratic and convex programming, and on stochastic programming continuous in time**.** In the study, the uncertainty of the stochastic linear problems is defined by stochastic processes. An adaptation of Benders decomposition algorithm to two-stage stochastic linear programs is discussed and used for two-stage stochastic linear programs with large or infinite number of scenarios. By methods of estimating expected values, an estimated optimal value for the problem is obtained. He discusses the efficiency of that estimator and the use of variance reduction technique to improve the estimation of the optimal value of the problem and to reduce the number of samples that are used by the algorithms. Two efficient algorithms to solve multi-stage stochastic linear programs are developed. One provides an upper bound for multi-stage stochastic linear programs with Gaussian right-hand-side. The second is an interior random vector algorithm for multi-stage stochastic linear program.

Through flexibility contracts, the risks due to uncertainty are shared between the manufacturer and the buyer, i.e., SC actors. The QF contract, which is one of these flexibility contracts, is a formal agreement specifically between a manufacturer and a buyer which explicitly specifies the buyer's attitude for updating prior forecasts of replenishment quantities. In most of the published works in the field, capacity restriction of the manufacturer who guarantees to replenish the amount within the bounds constructed with the contract parameters to the buyer, and the capacity allocation risk are not taken into account, which yields a cost, in fact. This risk happens to be due to the fact that there is an uncertain market demand with whom the buyer is facing, and so is the manufacturer due to the buyer's adjustable estimated replenishment amounts.

Hence, we first intend to analyze the behavior of the manufacturer in capacity planning while he has a limited capacity for production. Due to the obligation of providing the prescribed release amount to the buyer, in order to relax the capacity limitation constraint, the manufacturer is also given an outsourced production option for analysis of his incentives.

Moreover, in literature, the contracts are usually established between a buyer and a manufacturer, i.e., contract has two players. Thus, we are encouraged with the challenging analysis of the case where a second buyer is introduced to the system offering a QF contract to the manufacturer having a limited capacity for production. .

Thus far, in related works, the problem of stochastic demand in quantity flexibility contracts is tried to be overcome by constructing the deterministic version of the problem upon considering the worst case of the buyer's actual release schedule, i.e., her giving orders at the upper bound. Since the estimated replenishment amounts are determined prior to the realization of the uncertain market demand, and the actual ones after the realization, we aim to formulate the model of QF contract as a two-stage stochastic programming model with the intention of transferring the cost of uncertainty to the deterministic part of the problem as a recourse.

CHAPTER III

ENVIRONMENT AND MODELING

The purpose of supply chain management (SCM) is to improve the overall efficiency of a network of manufacturers, buyers and customers, while preserving a decentralized approach to the decision making process. Coordination between the supply chain (SC) actors can be achieved through appropriate exchange of information. In this respect, contracts, one of which is Quantity Flexibility (QF) contract, offer a large variety of possibilities to the mutual benefits of the contractors.

The environment where the SC actors exist in fact establishes the characteristics of the interactions between the actors in a contract framework. It also includes the type of information shared and the restrictions affecting the interactions between the parties. We make our analysis on the basis of the incentives of the SC actors and link their behaviors to individual and system wide performance. The attitudes of the actors who are offered QF contract, or actors who are offering a QF contract, are analyzed separately within the environment specified. Moreover, the changes in the attitudes of each party are examined thoroughly, when the benefit of the overall system is tried to be maximized. That is, we aim to present a structure for the analysis of quantity flexibility contracts, with the particular assumptions that seek the challenge for flexibility; suggest forecasting and ordering policies, for SC actors. Therefore, the environment that will be pictured constitutes the core of our study.

The organization of this chapter is as follows. In $3.1, the description of the environment analyzed, the definition of the problem and the underlying assumptions are given. In $3.2, the mathematical models for supply chain contractors individually, and for the integrated SC are illustrated. Finally, in $3.3, the stochastic programming models for each party and the integrated supply chain constructed are discussed.

3.1. ENVIRONMENT

We consider a supply chain composed of a single manufacturer and two buyers. The manufacturer produces a finished good that is immediately delivered to and sold by the buyers. The buyers sell the same product which faces a stochastic demand. They are an intermediary between the market and the manufacturer. There is no upstream supplier for the manufacturer. We assume that the manufacturer produces products immediately and delivers to the buyers just after the production and the buyers supply the market demand instantaneously. Since they face independent market demands, they are assumed to be independent.

The first buyer has a quantity flexibility contract already agreed upon, which is identified with the upward and downward flexibility parameters, ω^1 and α^1, respectively. In other words, by the QF contract, the buyer commits to purchase no less than a certain percentage ω^1 below the forecast and the manufacturer guarantees to deliver up to a certain percentage α^1 above the forecast. After observing the demand for the current period, the buyer can decide to order any quantity between (1- ω^1)q and (1+ α^1)q, where q is the initial order placed by the buyer and (ω^1, α^1)

are the QF parameters known by the manufacturer. The buyer is allowed to carry inventory and to backorder any unsatisfied demand for any number of periods. The unit inventory carrying and backordering costs, are hb and bb, respectively.

As an example from the industry, Nippon Otis, a manufacturer of elevator equipment, implicitly maintains such contract with Tsuchiya, its supplier of parts and switches (Lovejoy 1998). Another example from the electronics industry is Solectron, a leading contract manufacturer for many electronics firm. It has installed such agreements with both its customer and its raw material suppliers, implying that benefits may accrue to either end of such a contract (Ng 1997).

Upon the manufacturer's QF contract with the first buyer, the second buyer is introduced to the supply chain environment to study the effects of a new QF contract. We aim to analyze the second buyer's and the manufacturer's incentives when the second buyer is offered a QF contract with the manufacturer having another QF contract already signed with the first buyer. The purpose is to explore effects of the existing contract under limited production capacity for the manufacturer. At the beginning of the planning horizon, the contract flexibility parameters of the second buyer have not been specified. We try to analyze two cases where her flexibility parameters are determined in two different ways. In the first case, the second buyer finds out her optimal contract upward and downward flexibility parameters in the first period, and then carries on predicting and specifying her replenishment schedule according to the pre-found contract parameters. After the determination of the (ω^2, α^2) pair by herself, the contract parameters are informed to the manufacturer. The response of the manufacturer is explained below. In the second case, the manufacturer determines the contract flexibility parameters to be offered to the second buyer. Again, at the beginning of the planning horizon, he finds out the optimal flexibility parameters and offers to the second buyer. The second buyer is also allowed to carry inventory and to backorder any unsatisfied demand for any number of periods as in the first buyer's case. She is assumed to have the same unit inventory carrying and backordering costs as the first buyer; hb and bb, respectively.

The manufacturer provides the same products to the buyers who have QF contracts associated with the contract parameters specified beforehand. The manufacturer is given a limited capacity which is fixed so as to cover a large percentage (we take it as 80%) of average total demands of the two buyers. Moreover, two additional capacity options are offered to the manufacturer. The first one is subcontracting with a constant lead time of one period. The other one is immediate subcontracting with zero lead time for the current period in case of inadequate limited capacity and just arrived order from the subcontractor with a constant lead time of one period.

The manufacturer in turn, has his quantity flexibility parameters; $(\omega^{m1}, \alpha^{m1})$ and $(\omega^{m2}, \alpha^{m2})$ particular for the first and second buyer as if he has a QF contract with himself though he has no upstream supplier. These two flexibility pair sets are not in relation with the flexibility parameters of the buyers. The $(\omega^{m1}, \alpha^{m1})$ pair is stated at the beginning of the planning horizon, and the other flexibility pair, $(\omega^{m2}, \alpha^{m2})$ is the same as the one found in the two different cases which are explained in the introduction of the second buyer. The quantity flexibility parameters of the manufacturer can be seen as the flexibility granted to the capacity of the manufacturer himself. From a different point of view, they can be seen as restrictions generated for his release amounts. Thus, by making himself subject to the flexibility options or subject to some restrictions for his release amounts provided by his own QF parameters, the manufacturer is encouraged to manage his release amounts for buyers in line with the limited capacity and additional capacity options. As said by the QF contract, he guarantees to release the exact ordered amounts for the current period by the two buyers, thus, he is only allowed to carry inventory. The manufacturer has only unit costs of inventory carrying, hm, subcontracting, sm and immediate subcontracting, $subex$.

It is assumed that the market demand which the buyers face is uncertain and non-stationary and the demands for all periods are independent of each other. First, the two buyers meet the market demand realizations for the first period and generate the market demand forecasts for the coming periods over the finite planning horizon. Then, according to the contract flexibility and cost parameters, they construct their own replenishment schedules to be presented to the upstream manufacturer. These are comprised of each one's actual replenishment requests for the current period and estimated replenishment amounts for the remaining periods. They also determine their intended future replenishment amounts for the coming periods. However, these intended future replenishment decisions are not informed to the manufacturer. They can be seen as intended future self plans. The main function of the self plans is to develop a course of action with tighter bounds than those asked from the manufacturer. These have the possibility to be modified on a rolling horizon basis. As time passed, they will be the actual replenishment amounts of the current period.

According to the actual replenishment need for the current period, and estimated replenishment amounts for the later periods informed by the two buyers, the manufacturer guarantees to release the given actual amounts for the current period, unless they are outside the bounds denoted by QF contract. Upon taking the given capacity limit and subcontracting options into account, he also prepares the estimated release amounts and intended future release amounts for the coming periods according to his own estimates for the replenishments of the buyers. He has the same reasons (as the buyers) of being more conservative in inferring period-to-period variation for his internal plans. Not only, the estimated release amounts, but also the intended future release amounts can be modified on a rolling horizon basis.

If there happens to be a subcontracting decision for the second period, he gives the order of the amount to the subcontractor due to the one period subcontracting lead time. Unless the limited capacity and the just arrived order from the subcontractor are insufficient; the immediate subcontracting option is never employed. After the manufacturer supplies the exact release amounts requested by the buyers, the buyers satisfy their realized market demand totally or partially at their own discretion.

Then one period passes, the two buyers face the actual market demands for the second period and they in turn modify estimated market demands for the coming periods. Within the given bounds constructed by the contract flexibility parameters and estimated replenishment amounts determined in the first period, the buyers establish their new replenishment schedules. Then, they inform their schedules to the manufacturer. On the other hand, the manufacturer faced with the new replenishment schedules requested by the buyers reestablishes his new release schedules within his pre-specified flexibility bounds. Upon the reestablishment, he considers his capacity limit, and the amount ordered to the subcontractor in the first period, which has just arrived, and the subcontracting options for the following periods. Then, the manufacturer delivers the exact replenishment amounts once again, and the events carry on in the sequence stated above for the following periods.

The sequence of the events can be seen in Figure 3.1.

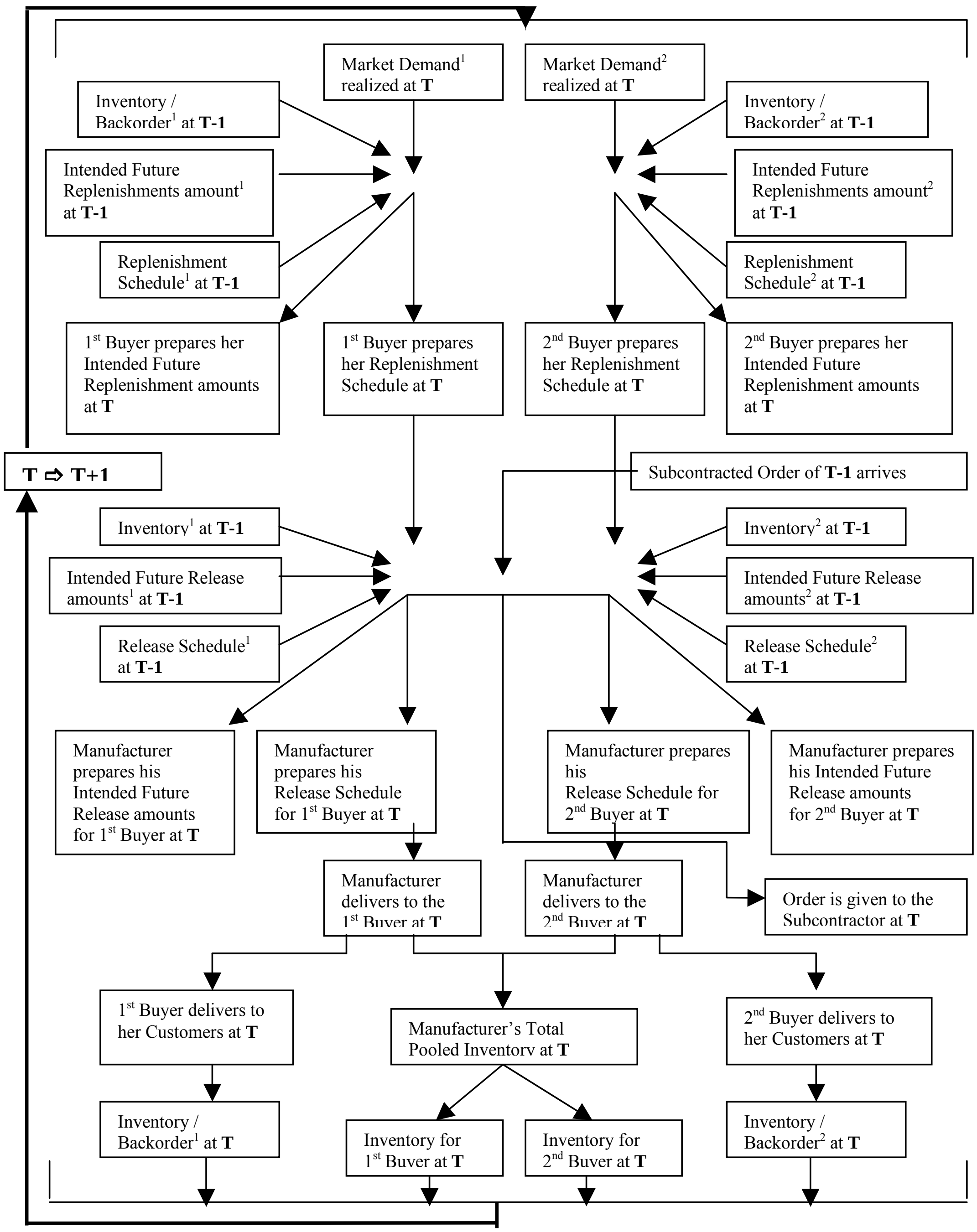

Figure 3.1 Sequences of the Events

In accordance with the sequence of events displayed above, and the environment illustrated in Figure 3.2, the two buyers face the realized market demand for the current period. After the realizations of market demand, the buyers determine their actual replenishment requests, for the current period, according to their initial carried and backordered amounts without violating the bounds specified by the estimated replenishment amounts settled on in the previous period. In the current period, not only the estimated replenishment, but also the intended future replenishment amounts for the following periods have the option to be adjusted. The buyers try to estimate these replenishment amounts in such a way that the bounds which will be constructed by them will neither restrict nor boost their actual replenishment amounts in the coming periods. That is, the buyers have tradeoffs in estimating the replenishment amounts, and in building the bounds such that they will satisfy the realized demand without carrying too much inventory and without too much backordering. Moreover, when low market demand is realized, by the QF contract, they have the option of ordering less than their estimated replenishment amounts from the manufacturer within the bounds constructed by the QF contract. Or, when the opposite occurs, they have the opportunity to request more than their estimated replenishment amounts without violating the bounds established.

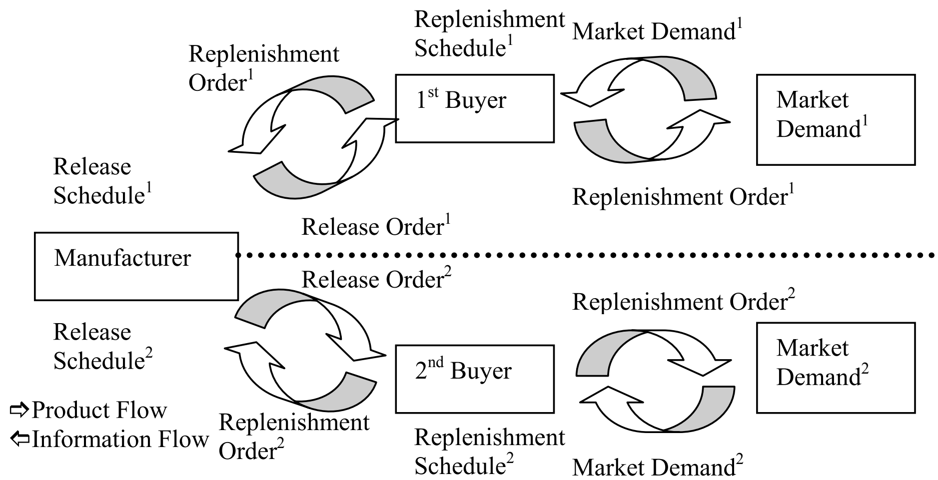

Figure 3.2 Picture of the Environment

The manufacturer guarantees to release exact replenishment amounts received from the buyer and tries to manage his limited capacity with additional subcontracting options. Since the given estimated replenishments of the buyers have the option to be adjusted, the manufacturer, in fact, face with uncertain actual replenishment amounts to be asked by the buyers for the following periods. Therefore, the manufacturer also has a tradeoff between allocating his capacity in full, ordering large amounts to the subcontractor, hence carry inventory; versus restricting his capacity, using the immediate subcontracting option in the current period, which is highly expensive.

Furthermore, the same type of product is provided to both buyers. Hence, for each buyer individually, the manufacturer has the option of pooling inventory. This is separated from the total inventory for the satisfaction of the actual replenishment amounts by the actual release amounts for the buyers. The potential for inventory carrying of the manufacturer can be seen precisely in Figure 3.3.

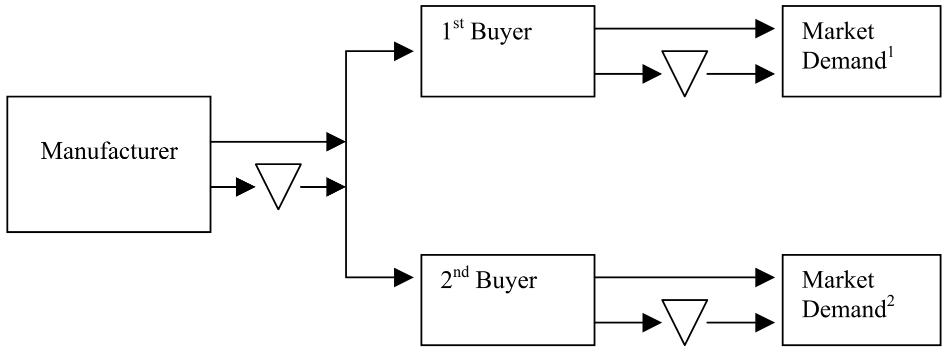

Figure 3.3 Scheme of Product Delivery

According to Figure 3.3, the manufacturer pools inventory into a single storage, and the required amounts particular for each buyer are delivered from this single storage through two separate branches. By this option, the manufacturer has the chance to exchange part of the actual release amount of the buyer ordering a lower replenishment with the other buyer ordering a higher replenishment amount.

Similar to the use of common inventory, the manufacturer can also increase the total amount of capacity to be allocated differently for the actual release amounts to the two buyers through the just-arrived shipment from the subcontractor. By introducing the just-arrived shipment into the common use of actual release amounts for each buyer, when one of the buyers orders larger, and the other orders less, the manufacturer is given the opportunity to direct greater part of the order to one of the buyers. We think this substitution helps accept higher flexibility needs of a second buyer.

3.2. MODELING

To evaluate the impact of a given contract on the behavior of the SC actors and on the performance of the system, it is necessary to perform a quantitative analysis. Analytically, this necessitates building a mathematical model that describes the environment (demand, capacity and subcontracting decisions, and sequence of the events stated in the previous section.) and the use of mathematical tools to treat these models. To illustrate our point, we focus on the model for quantity flexibility contract presented by Tsay and Lovejoy (1999). Different from Tsay and Lovejoy, we add the second buyer into the supply chain environment. We intend to analyze not only the second buyer's incentives when she is offered a QF contract with a manufacturer, but also the manufacturer's incentives when he has a QF contract with a buyer and offers a QF contract to another buyer. Furthermore, a capacity limitation for the release amounts of the manufacturer is introduced. Also, two subcontracting options with constant lead times of one period and zero period, are included in the capacity consideration. That is, the manufacturer is given costly capacity options to be able to guarantee the replenishment schedules formed by the buyers.

In this study, we try to address the objectives; (i) to provide a structure for the analysis of quantity flexibility contracts, with the assumption of non-stationary and uncertain market demand that offer a challenge for flexibility; (ii) suggest forecasting and ordering policies, for buyers who are obliged to purchase a certain fraction of their estimates, for manufacturer who guarantees to provide a certain amount of the buyer's replenishment amounts; (iii) link all these behaviors to individual and system wide performance, and (iv) see the impact of parameters on the behaviors.

Our supply chain planning problem involves medium and short term decision types. The former, includes outsourced production capacity and range setting decisions, and the latter comprises of decisions on production, inventory holding, and allocation of flexible capacity. Medium term typically refers to months, whereas short term is in the order of days or weeks.

In order to carry out quantitative analysis for the described multi period supply chain problem, we construct models to be presented immediately after the related notations are displayed.

BUYERS' CASE:

The notations used for the first and second buyers are as in the following;

T :number of periods in the finite planning horizon.

$M_0b(t)$:realized demand of buyer b in the current period t, where b=1, 2.

$M_0b(t+j)$:random demand occurrence of buyer b in period (t+j), where b=1, 2, and j=1,…,T-1.

$f_0b(t+j)$:actual replenishment amount of buyer b in period (t+j), which is intended future replenishment amount, for all periods except current period t. b=1, 2 and j=0,…,T-1.

$f_jb(t)$:estimated replenishment amount of period (t+j) of buyer b, which is passed on to the manufacturer in period t. b=1, 2, and j=1,…, T-1.

$invb(t+j)$:amount of ending inventory of buyer b in period (t+j), where b=1, 2 and j=0,…, T-1.

$backb(t+j)$:amount of backordered demand by buyer b in period (t+j), where b=1, 2 and j=0,…,T-1.

(ω^b, α^b) :downward and upward flexibilities for buyer b, where b=1,2.

$\omega^b = [\omega_1^b, \omega_2^b, \omega_3^b, ..., \omega_{T-1}^b]$, $\alpha^b = [\alpha_1^b, \alpha_2^b, \alpha_3^b, ..., \alpha_{T-1}^b]$

(Ω^b, A^b) :cumulative downward and upward flexibilities for buyer b, where b=1,2.

$\Omega^b = [\Omega_0^b, \Omega_1^b, \Omega_2^b, ..., \omega_{T-1}^b]$, $\mathrm{A}^b = [\mathrm{A}_0^b, \mathrm{A}_1^b, \mathrm{A}_2^b, ..., \mathrm{A}_{T-1}^b]$

hb :unit inventory holding cost for both buyers per period.

bb :unit backordering cost for both buyers per period.

There is a relation between (ω^b, α^b) and (Ω^b, A^b), which can be expressed as in the following equations;

$[1-\Omega_j^b] = \prod_{q=1}^{j}(1-\omega_q^b)$ and $[1+\mathrm{A}_j^b] = \prod_{q=1}^{j}(1+\alpha_q^b)$

The number of periods in the finite planning horizon does not differ as time passes. That is, the horizon length does not decrease. Thus, the current period is always represented with the same index t, and the later periods with the index (t+j), as time passes. It is illustrated more precisely in Figure 3.4. Also, from the figure, the relation between the actual replenishment amounts, $f_0 b(t+j)$ and the estimated replenishment amounts, $f_j b(t)$ can be captured.

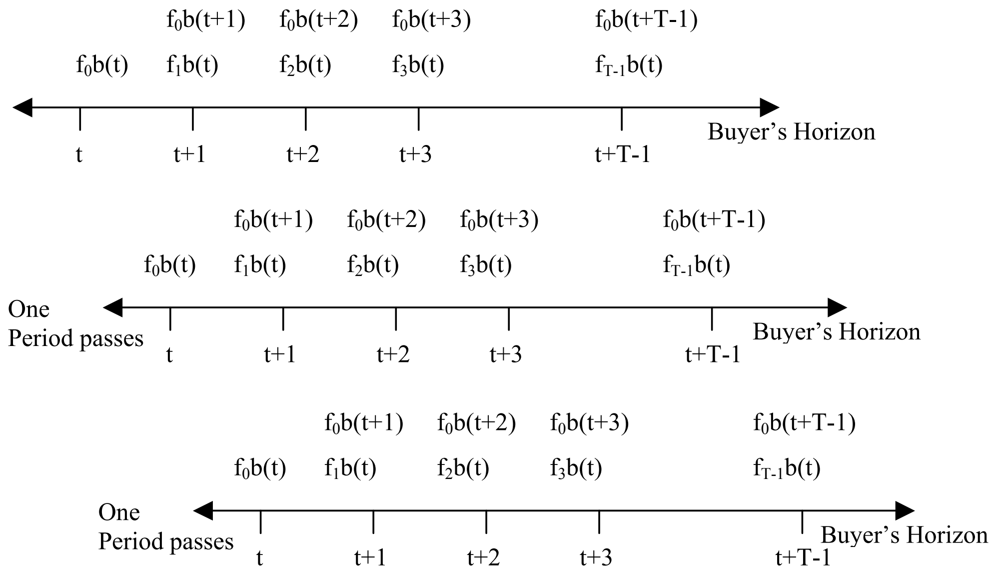

Figure 3.4 Notation Changes on a Rolling Horizon

<u>Buyers' Model (BUY-DET$_b$):</u>

The model for the buyer b can be stated briefly as in the following;

$$\text{Min} \quad \sum_{j=0}^{T-1}[hb \times invb(t+j) + bb \times backb(t+j)]$$

s.t.

$$invb(t+j) - backb(t+j) = invb(t+j-1) - backb(t+j-1) + f_0 b(t+j) - M_0 b(t+j)$$

$$\forall j = 0,\ldots,T-1 \qquad (1)$$

$$(1-\omega_{j+1}^{b}) f_{j+1} b(t-1) \le f_j b(t) \le (1+\alpha_{j+1}^{b}) f_{j+1} b(t-1) \qquad \forall j = 0,\ldots,T-2 \qquad (2)$$

$$(1-\Omega_j^{b}) f_j b(t) \le f_0 b(t+j) \le (1+\mathrm{A}_j^{b}) f_j b(t) \qquad \forall j = 0,\ldots,T-1 \qquad (3)$$

The objective function of the buyer's model is the minimization of inventory and backordering costs.

(1) Inventory Balance constraints, imply the market demand in period t, $M_0b(t+j)$ can be satisfied totally or partially by the actual replenishment amount in period (t+j), $f_0b(t+j)$.

(2) Incremental Revision constraints, imply the estimated replenishment amount for future period (t+j), $f_jb(t)$, can not be revised upward by a fraction of more than $\alpha_{j+1}{}^{b}$ or downward by more than $\omega_{j+1}{}^{b}$ of the estimated replenishment amounts determined in the previous period (t+j-1), $f_{j+1}(t-1)$.

(3) Cumulative Flexibility constraints, imply the estimated replenishment amount for period (t+j) determined in the current period t, $f_jb(t)$, suggests bounds on the decision for the actual replenishment amount for period (t+j), $f_0b(t+j)$.

In other words, the replenishment amounts for the second and later periods (t+j) where j=1,…,T-1, are estimated in the current period t. These estimated replenishment amounts, $f_jb(t)$'s, establish bounds for the intended future replenishment amounts for period (t+j), $f_0b(t+j)$. The incremental revision constraints puts bounds on estimated replenishment amounts based on earlier estimates and the cumulative constraints puts bounds on actual replenishment amounts based on the estimated replenishment amounts.

MANUFACTURER'S CASE:

For the manufacturer, the following notations are used;

T :number of periods in the finite planning horizon.

$f_0b(t)$:realized actual replenishment amount of buyer b in the current period t, where b=1, 2.

$f_0 b(t+j)$:random occurrence of actual replenishment of buyer b in period (t+j), where b=1, 2 and j=1,…T-1.

$r_0 b(t+j)$:actual release amount for the request of buyer b in period (t+j), which is intended future release amount except r0b(current period t). b=1, 2 and j=0,…,T-1.

$r_j b(t)$:estimated release amount of period (t+j) for buyer b in period t, where b=1, 2, and j=1,..., T-1.

$invmb(t+j)$:amount of ending inventory for buyer b in period (t+j), where b=1, 2 and j=0,…, T-1.

$invmpb(t+j)$:amount of inventory taken from the total pooled inventory for buyer b in period (t+j), for the usage in period (t+1), where b=1, 2 and j=0,…,T-1.

$SUB(t)$:order arrived in period t, which is given to the subcontractor in period (t-1).

$sub(t+j)$:amount of order given to the subcontractor in period (t+j-1) and to have delivered in period (t+j), where j=0,…,T-1.

$sub\exp b$:amount of order given to the subcontractor in the current period t, and to be delivered in that period, where b=1,2.

$cap(t+j)$:amount of capacity used for the sum of the actual release amounts in period (t+j), where j=0,…,T.

CAP :fixed capacity available through all periods.

$(\omega^{mb}, \alpha^{mb})$:downward and upward flexibilities for the manufacturer particular for buyer b, where b=1, 2.

$\omega^{mb} = [\omega_1^{mb}, \omega_2^{mb}, \omega_3^{mb}, ..., \omega_{T-1}^{mb}]$, $\alpha^{mb} = [\alpha_1^{mb}, \alpha_2^{mb}, \alpha_3^{mb}, ..., \alpha_{T-1}^{mb}]$

(Ω^b, A^b) :cumulative downward and upward flexibilities for the manufacturer for particular buyer b, where b=1,2.

$\Omega^{mb} = [\Omega_0^{mb}, \Omega_1^{mb}, \Omega_2^{mb}, ..., \omega_{T-1}^{mb}]$, $\mathrm{A}^{mb} = [\mathrm{A}_0^{mb}, \mathrm{A}_1^{mb}, \mathrm{A}_2^{mb}, ..., \mathrm{A}_{T-1}^{mb}]$

hm :unit inventory holding cost for the manufacturer per period.

sm :unit subcontracting cost.

$subex$:unit immediate subcontracting cost in the current period t.

There is also a relation between the cumulative and incremental flexibilities as in the buyers' case. That is, $[1-\Omega_j^{mb}] = \prod_{q=1}^{j}(1-\omega_q^{mb})$ and $[1+\mathrm{A}_j^{mb}] = \prod_{q=1}^{j}(1+\alpha_q^{mb})$

Manufacturer's Model (MAN-DET):

The model for the manufacturer can be presented as follows;

Min $\quad \sum_{b=1}^{2}\sum_{j=0}^{T-1}[hm \times invmb(t+j)] + \sum_{j=1}^{T-1} sm \times sub(t+j) + \sum_{b=1}^{2} subex \times sub\exp b$

s.t.

$$invm1(t+j) = invmp1(t+j-1) + sub\exp 1 + r_0 1(t+j) - f_0 1(t+j)$$

$$\forall j = 0,\mathrm{K}\ ,T-1 \tag{1}$$

$$(1-\omega_{j+1}^{m1})r_{j+1}1(t-1) \le r_j 1(t) \le (1+\alpha_{j+1}^{m1})r_{j+1}1(t-1) \quad \forall j = 0,\mathrm{K}\ ,T-2 \tag{2}$$

$$(1-\Omega_j^{m1})r_j 1(t) \le r_0 1(t+j) \le (1+\mathrm{A}_j^{m1})r_j 1(t) \quad \forall j = 0,\mathrm{K}\ ,T-1 \tag{3}$$

$$invm2(t+j) = invmp2(t+j-1) + sub\exp 2 + r_0 2(t+j) - f_0 2(t+j)$$

$$\forall j = 0,\mathrm{K}\ ,T-1 \tag{4}$$

$$(1-\omega_{j+1}^{m2})r_{j+1}2(t-1) \le r_j 2(t) \le (1+\alpha_{j+1}^{m2})r_{j+1}2(t-1) \quad \forall j = 0,\mathrm{K}\ ,T-2 \tag{5}$$

$$(1-\Omega_j^{m2})r_j 2(t) \le r_0 2(t+j) \le (1+\mathrm{A}_j^{m2})r_j 2(t) \qquad \forall j = 0,\mathrm{K}\ ,T-1 \tag{6}$$

$$invm1(t+j) + invm2(t+j) = invmp1(t+j) + invmp2(t+j)$$

$$\forall j = 0,\mathrm{K}\ ,T-1 \tag{7}$$

$$r01(t) + r02(t) \le cap(t) + SUB(t) \tag{8}$$

$$r01(t+j)+r02(t+j)\le cap(t+j)+sub(t+j) \qquad \forall j=1,\ldots,T-1 \qquad (9)$$

$$cap(t+j)\le CAP \qquad \forall j=0,\ldots,T-1 \qquad (10)$$

The objective function of the manufacturer's model is the minimization of inventory carrying, subcontracting and immediate subcontracting costs.

(1) and (4), Inventory Balance constraints, imply the actual replenishment amount of buyer b in period (t+j), $f_0b(t+j)$ should be satisfied exactly, by the actual release amount in period (t+j), $r_0b(t+j)$.

(2) and (5), Incremental Revision constraints, imply the estimated release amount for future period (t+j), $r_jb(t)$, can not be revised upward by a fraction of more than α_{j+1}^m or downward by more than ω_{j+1}^m of the estimated release amount determined in the previous period (t+j-1), $r_{j+1}b(t-1)$.

(3) and (6), Cumulative Flexibility constraints, imply the estimated release amount for period (t+j) determined in the current period t, $r_jb(t)$, suggests bounds on the decision for the actual release amount for period (t+j), $r_0b(t+j)$.

(7) Inventory Pooling constraints, imply inventory carrying decisions resulting from the satisfaction of the actual replenishment amounts are served by the total pooled inventory from which the required amounts can be released separately.

(8), (9), and (10) Capacity Limitation constraint, imply the sum of the actual release amounts in period (t+j) for both buyers can not exceed the capacity limit. We have a costly option to each of the given constant capacity limit for later periods. Due to one period lead time subcontracting, the order given in the period t won't be on hand until period (t+1).

Quantity Flexibility contracts, help improve the joint performance of the buyers and the manufacturer acting independently within the contract framework. To this end, buyers face random market demand. The buyers only know the actual market demand for the current period and they forecast for the coming periods. After the realization of market demand of the current period, they convey information on the actual replenishment and estimated replenishment amounts that they will request, to the manufacturer. On the other hand, the manufacturer has his own ordering information for the buyers, where only the actual replenishment amounts for the current period is identified exactly as soon as he is informed and later periods' actual replenishment amounts are random. In other words, the manufacturer has no information about the market demand. The manufacturer only knows the exact actual replenishment amounts for the current period, and forecasts the replenishment amounts for the coming periods for his future plans. Hence, there is information discrepancy between the SC parties, where the buyers face market demand, and the manufacturer faces replenishment amounts.

INTEGRATED SUPPLY CHAIN ENVIRONMENT:

Under the consideration of random market demand assumption, we construct an integrated supply chain model, where the buyers' actual replenishment amounts for the current period and intended future replenishment amounts for the following periods, are directly and immediately transmitted to the manufacturer as their exact amounts. However, in the separate case, the buyers did not inform their intended future replenishment amounts to the manufacturer. That is to say, in the integrated SC model, there is no information asymmetry between the supply chain actors. All information about the market demand, intended future replenishment decisions of the buyers are passed on to the manufacturer, so are the information of intended future release and subcontracting decisions of the manufacturer to the buyers.

All assumptions and particular parameters stated before the separate formulations of the models of SC actors are also valid for the integrated supply chain model.

Then, the model constructed for the integrated supply chain can be presented as follows;

Integrated Supply Chain Model (INTSC-DET):

Min $$\sum_{b=1}^{2}\sum_{j=0}^{T-1}[hb \times invb(t+j) + bb \times backb(t+j)] +$$

$$\sum_{b=1}^{2}\sum_{j=0}^{T-1}[hm \times invmb(t+j)] + \sum_{j=1}^{T-1} sm \times sub(t+j) + \sum_{b=1}^{2} subex \times sub\exp b$$

s.t.

Equations (1), (2), and (3) in the formulations of BUY-DET$_1$ and BUY-DET$_2$.

Equations (2), (3), (5), (6), (7), (8), (9), and (10) in the formulation of MAN-DET.

$$invm1(t+j) = invmp1(t+j-1) + sub\exp 1 + r_0 1(t+j) - f_0 1(t+j) \quad \forall j = 0,\ldots,T-1 \quad (1)$$

$$invm2(t+j) = invmp2(t+j-1) + sub\exp 2 + r_0 2(t+j) - f_0 2(t+j)$$

$$\forall j = 0,\ldots,T-1 \qquad (2)$$

The objective function of the integrated SC model is the minimization of aggregated inventory carrying and backordering costs of the buyers; inventory carrying, subcontracting and immediate subcontracting costs of the manufacturer.

(1) and (2), Inventory Balance constraints of the manufacturer for each buyer, imply that the actual replenishment amount of buyer b in period (t+j), $f_0b(t+j)$, should be satisfied totally, by the actual release amount in period (t+j), $r_0b(t+j)$. In these constraints, $f_0b(current\ period\ t)$ is the actual replenishment amount of buyer b, and $f_0b(t+j)$ is the intended future replenishment amount for period (t+j) determined by buyer b, that is, $f_0b(t+j)$'s are not random.

In the buyer's case, $M_01(t+j)$ and $M_02(t+j)$'s in inventory balance constraints are the random demand occurrences for the first and second buyers, respectively. For the manufacturer's case, $f_0b(t+j)$'s in inventory balance constraints are the random actual replenishment amounts of each buyer. In this integrated supply chain model, since $f_0b(t+j)$'s become a common decision for both parties, only $M_0b(t+j)$'s of each buyer are random demand occurrences for the buyers, and the manufacturer faces the determined actual replenishment amounts.

3.3. STOCHASTIC MODELLING

In view of the fact that the market demand is not deterministic, the problem under consideration happens to be a stochastic linear program. For the involvement of the stochastic demand into the problem, a scenario based approach is utilized. A scenario can be defined as a combination of the realizations of the stochastic variables, i.e., market demand for all periods in the planning horizon.

In our study, the stochastic variables for the first and second buyers are the uncertain market demand. Since, these variables occur in inventory balance constraints, the actual replenishment decision variables are constructed scenario based, so are the inventory carrying and backordering decision variables.

However, for the manufacturer, the actual replenishment amounts are the stochastic variables. Thus, the actual release decision variables in inventory balance constraints are constructed scenario based. Since the actual release decision variables are involved also in the capacity limitation constraints where the subcontracting decision variables are stated, these variables are also scenario based. The subcontracting decisions for each period are constructed according to the combination of pairs of scenarios of the actual replenishment amounts of the buyers. For the manufacturer, there will be a unique set of decisions which consists of the amounts of inventory carried, inventory pooled, actual release amounts for the first and second buyer, and amount of order to be given to the subcontractor, for each period in a given scenario.

We introduce the assumption that the random market demands are described by finitely many mutually exclusive scenarios each with its particular probability. That is, the random market demand, M_{t+1}, M_{t+2},…M_{t+T-1}, is assumed to have a discrete probability distribution. $M_{t,sc}$ is demand with probability p_{sc}, where sc denotes the particular scenario. Scenarios can be represented by scenario trees, where each branch correspond to a scenario, sc. This makes it possible to formulate the deterministic equivalent of the problem as a finite dimensional mathematical programming problem, where deterministic variables are continuous and the random variables are discrete. Many of the studies in the field employ discrete probability distribution assumption in order to solve the stochastic programming models. In case random variables are continuous; the formulation will result in nonlinearities.

Furthermore, in the scenario based decision problem we are formulating, we have to include nonanticipativity constraints, implying that we can not anticipate the future. A solution to a stochastic programming problem, in the form of a sequence of responses to random events, is nonanticipative if each given response depends only on the past events and not on future events. That is, the future is uncertain and so today's decision can not take the advantage of knowledge of the future. For instance, when the levels of a scenario tree are taken into consideration, scenarios with a common history, i.e., who inherit from the same branch of the tree, must (logically) have the same set of decisions as the common ancestors.

BUYERS' CASE:

According to the scenario based approach with discrete random variables, we have generated a scenario tree with 4 levels for the buyers. This represents 4 time periods in the planning horizon for the buyers. On the first level, there is only one demand value with probability one, since the market demand of the current period is a realized amount of a random demand process. The same holds true for the second buyer. The scenario tree, which is the same in principle for both buyers, is presented in Figure 3.5.

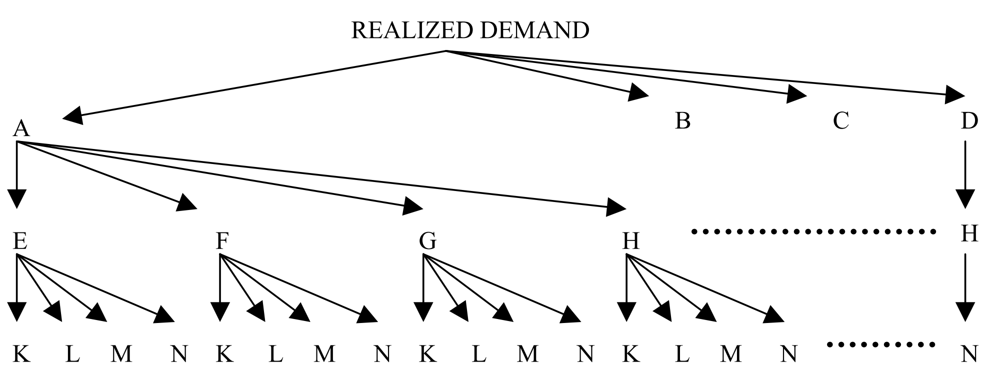

Figure 3.5 Scenario Tree of the First and Second Buyers

In the figure above, following the current period, i.e., the top of the tree, in the second and later periods, there are 4 possible demand occurrences.

From the tree in the figure, the nonanticipativity occurrences can be easily captured. For instance, every one of the 64 scenarios inherits from a single node resulting in the same carried inventory or backordered amount of the first period. For instance, the first 16 scenarios, at the bottom of the scenario tree, stem from a single branch on the second level, implying that they have the same value for the ending inventory or backordered amounts in the second period. Thus, scenarios, which stem from the same branch, i.e., which share a common history, have the same set of inventory carrying and backordering decisions to inherit from.

For the stochastic programming models, the notations are somewhat modified. The notations used for the buyers are the following;

T :number of periods in the finite planning horizon.

SC :number of scenarios generated.

$sc_b^{l,k}$:scenarios at level l with common ancestor k, where l=1,…,T-1.

$M_0b(t, sc_b)$:actual market demand of buyer b in the current period t under scenario sc_b, where b=1,2 and sc_b=1,…SC. It has identical values for all scenarios, 1 through SC.

$M_0b(t+j, sc_b)$:random demand occurrence of buyer b in period (t+j) under scenario sc_b , where b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$f_0b(t+j, sc_b)$:actual replenishment amount of buyer b in period (t+j) under scenario sc_b, which is intended future replenishment for all periods except current period t. b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$f_j b(t)$:estimated replenishment amount of period (t+j) of buyer b in period t, which is passed onto the manufacturer. b=1, 2 and j=0,…,T-1. It is assumed that $f_j b(t)$'s are statistically independent of $f_0 b(t+j, sc_b)$'s.

$invb(t+j, sc_b)$:amount of ending inventory of buyer b in period (t+j) under scenario sc_b, where b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$backb(t+j, sc_b)$:amount of backordered demand by buyer b in period (t+j) under scenario sc_b, where b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$probb(sc_b)$:probability associated with scenario sc_b for buyer b, where b=1,2 and sc_b=1,…,SC.

The (ω^b, α^b) and (Ω^b, A^b) pair, hb and bb notations are same as in BUY-DET$_1$ and BUY-DET$_2$.

Buyers' Stochastic Model (BUY-STOCH$_b$):

Then, the stochastic programming model for the buyers can be stated briefly as in the following;

$$\text{Min} \quad \sum_{sc_b=1}^{SC} \sum_{j=0}^{T-1} probb(sc_b)[hb \times invb(t+j, sc_b) + bb \times backb(t+j, sc_b)]$$

s.t.

$$invb(t+j, sc_b) - backb(t+j, sc_b) =$$
$$invb(t+j-1, sc_b) - backb(t+j-1, sc_b) + f_0 b(t+j, sc_b) - M_0 b(t+j, sc_b)$$

$$\forall j = 0, \ldots, T-1 \; and \; \forall sc_b = 1, \ldots, SC \tag{1}$$

$$(1-\omega_{j+1}^b) f_{j+1} b(t-1) \le f_j b(t) \le (1+\alpha_{j+1}^b) f_{j+1} b(t-1) \quad \forall j = 0, \ldots, T-2 \tag{2}$$

$$(1-\Omega_j^b) f_j b(t) \le f_0 b(t+j, sc_b) \le (1+\mathrm{A}_j^b) f_j b(t)$$

$$\forall j = 0,\ldots,T-1 \;\; and \;\; \forall sc_b = 1,\ldots,SC \tag{3}$$

$$invb(t+j, sc_b{}^{l,k}) = invb(t+j, sc_b'^{\,l,k})$$

$$\forall j = 0,\ldots,T-1 \;\; and \;\; \forall sc_b{}^{l,k} = 1,\ldots,SC \tag{4}$$

The objective function of the buyer's model is the minimization of the expected inventory carrying and expected backordering costs.

(1) Inventory Balance constraints, imply the market demand in period (t+j) under scenario sc_b, $M_0b(t+j, sc_b)$ can be satisfied totally or partially, by the actual replenishment amount in period (t+j) under scenario sc_b, $f_0b(t+j, sc_b)$.

(2) Incremental Revision constraints, imply estimated replenishment amount for future period (t+j), $f_jb(t)$ can not be revised upward by a fraction of more than $\alpha_{j+1}{}^{b}$ or downward by more than $\omega_{j+1}{}^{b}$ of the estimated replenishment amounts determined in the previous period, (t+j-1), $f_{j+1}b(t-1)$.

(3) Cumulative Flexibility constraints, imply the estimated replenishment amount for period (t+j) determined in the current period t, $f_jb(t)$, suggests bounds on the decision for the actual replenishment amount for period (t+j) under scenario sc_b, $f_0b(t+j, sc_b)$.

(4) Nonanticipativity constraints, imply the scenarios having a common history have the same set of inventory carrying and backordering decisions to inherit from. That is, they aren't identical for all periods but start with identical figures so much as the common ancestors.

MANUFACTURER'S CASE:

The manufacturer faces two separate and independent actual replenishment occurrences at random for the two buyers. We assume that these random replenishment amounts are also described by finitely many mutually exclusive scenarios that are independent from each buyer's scenarios.

In accordance with the scenario based approach, we constitute two scenarios trees specific to the two buyers with 4 levels, representing 4 time periods. One of the scenario trees which is identical for both buyers are presented in Figure 3.6.

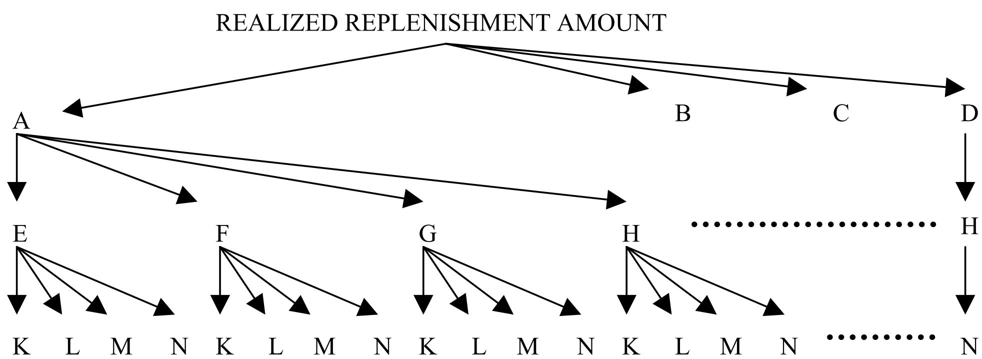

Figure 3.6 Scenario Tree of the Manufacturer

In the first period, that is the first levels of the scenario trees, there are two exact values with probability of one, on behalf of the realized actual replenishment amounts of the first and second buyers, respectively. In the second period, and later periods, there are 4 possible replenishment values for the first buyer and another 4 for the second buyer in their own scenario trees.

The manufacturer is subject to two different scenarios related to the first and second buyer. He considers all combinations of the actual release amount decisions under their related scenarios in order to determine the amount of order to be given to the subcontractor and the amount of limited capacity to be used. Furthermore, in order to determine how many units to pool into the total inventory, the manufacturer takes all combinations of the amount of inventory carrying decisions under all scenarios generated for the buyers individually.

As in the buyer case, there are also nonanticipativity constraints for the inventory carrying and inventory pooling decisions. That is to say, scenarios that originate from the same branch will have the same set of inventory carrying and pooling decisions.

For the manufacturer, the following notations are used;

T :number of periods in the finite planning horizon.

SC :number of scenarios generated.

${sc_b}^{l,k}$:scenarios at level *l* with common ancestor k, where *l*=1,…,T-1.

$f_0b(t, sc_b)$:actual replenishment amount of buyer b in the current period t under scenario sc_b , where b=1,2 and sc_b=1,…,SC. It has identical values for all scenarios 1 through SC.

$f_0b(t+j, sc_b)$:random occurrence of actual replenishment amount of buyer b estimated in period (t+j) under scenario sc_b, where b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$r_0b(t+j, sc_b)$:actual release amount for the request of buyer b in period (t+j) under scenario sc_b, which is intended future release for all periods except current period t. b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$r_jb(t)$:estimated release amount of period (t+j) for buyer b in period t, where b=1, 2 and j=0,…,T-1.

$invmb(t+j, sc_b)$:amount of ending inventory for buyer b in period (t+j) under scenario sc_b, where b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$invmpb(t+j, sc_b)$:amount of inventory taken from the total pooled inventory for buyer b in period (t+j) under scenario sc_b for the usage in period (t+j+1) under scenario sc_b, where b=1, 2, j=0,…,T-1 and sc_b=1,…,SC.

$SUB(t)$:order arrived in period t, which is given to the subcontractor in period (t-1).

$sub(t+j, sc_1, sc_2)$:amount of order given to the subcontractor in period (t+j-1) and to have delivered in period (t+j) under the combination of scenarios sc_1 and sc_2, where j=0,…T-1, sc_1=1,…,SC and sc_2=1,…,SC.

$cap(t+j, sc_1, sc_2)$:amount of capacity used for the sum of the actual release amounts in period (t+j) under the combination of scenarios sc_1 and sc_2, where j=0,…T-1, sc_1=1,…SC and sc_2=1,…,SC.

$probsb(sc_b)$:probability associated with scenario sc_b of the manufacturer for buyer b, where b=1,2 and sc_b=1,…,SC.

The $sub\exp b$, CAP, $(\omega^{mb}, \alpha^{mb}), (\Omega^{mb}, \mathrm{A}^{mb})$ hm, sm, and $subex$ notations are same as in MANUF-DET.

Manufacturer's Stochastic Model (MAN-STOCH):

The model for the manufacturer can be displayed as follows;

$$\text{Min} \quad \sum_{b=1}^{2}\sum_{sc_b}^{SC}\sum_{j=0}^{T-1} probsb(sc_b)[hm \times invmb(t+j, sc_b)] +$$

$$\sum_{sc_1}^{SC}\sum_{sc_2}^{SC}\sum_{j=1}^{T-1} probs1(sc_1)\, probs2(sc_2)[sm \times sub(t+j, sc_1, sc_2)] +$$

$$\sum_{b=1}^{2} subex \times sub\exp b$$

s.t.

$$invm1(t+j, sc_1) = invmp1(t+j-1, sc_1) + sub\exp 1 + r_0 1(t+j, sc_1) - f_0 1(t+j, sc_1)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_1 = 1, \ldots, SC \qquad (1)$$

$$(1-\omega_{j+1}^{m1}) r_{j+1} 1(t-1) \le r_j 1(t) \le (1+\alpha_{j+1}^{m1}) r_{j+1} 1(t-1) \qquad \forall j = 0, \ldots, T-2 \qquad (2)$$

$$(1-\Omega_j^{m1}) r_j 1(t) \le r_0 1(t+j, sc_1) \le (1+\mathrm{A}_j^{m1}) r_j 1(t)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_1 = 1, \ldots, SC \qquad (3)$$

$$invm2(t+j, sc_2) = invmp2(t+j-1, sc_2) + sub\exp 2 + r_0 2(t+j, sc_2) - f_0 2(t+j, sc_2)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_2 = 1, \ldots, SC \qquad (4)$$

$$(1-\omega_{j+1}^{m2}) r_{j+1} 2(t-1) \le r_j 2(t) \le (1+\alpha_{j+1}^{m2}) r_{j+1} 2(t-1) \quad for\, j = 0, \ldots, T-2 \qquad (5)$$

$$(1-\Omega_j^{m2}) r_j 2(t) \le r_0 2(t+j, sc_2) \le (1+\mathrm{A}_j^{m2}) r_j 2(t)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_2 = 1, \ldots, SC \qquad (6)$$

$$invm1(t+j, sc_1) + invm2(t+j, sc_2) = invmp1(t+j, sc_1) + invmp2(t+j, sc_2)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_1 = 1, \ldots, SC \; and \; sc_2 = 1, \ldots, SC \qquad (7)$$

$$r01(t, sc_1) + r02(t, sc_2) \le cap(t, sc_1, sc_2) + SUB(t)$$

$$sc_1 = 1, \ldots, SC \; and \; sc_2 = 1, \ldots, SC \qquad (8)$$

$$r01(t+j, sc_1) + r02(t+j, sc_2) \leq cap(t+j, sc_1, sc_2) + sub(t+j, sc_1, sc_2)$$

$$\forall j = 1, \ldots, T-1 \ and \ sc_1 = 1, \ldots, SC \ and \ sc_2 = 1, \ldots, SC \quad (9)$$

$$cap(t+j, sc_1, sc_2) \leq CAP$$

$$\forall j = 0, \ldots, T-1 \ and \ sc_1 = 1, \ldots, SC \ and \ sc_2 = 1, \ldots, SC \quad (10)$$

$$invmb(t+j, sc_b{}^{l,k}) = invmb(t+j, sc_b'^{l,k})$$

$$\forall j = 0, \ldots, T-1 \ and \ \ \forall b = 1,2 \ and \ \forall sc_1{}^{l,k} = 1, \ldots, SC \quad (11)$$

$$invmpb(t+j, sc_b{}^{l,k}) = invmpb(t+j, sc_b'^{l,k})$$

$$\forall j = 0, \ldots, T-1 \ and \ \ \forall b = 1,2 \ and \ \forall sc_1{}^{l,k} = 1, \ldots, SC \quad (12)$$

$$sub(t+1, sc_1, sc_2) = sub(t+1, sc_1', sc_2')$$

$$\forall sc_1 = 1, \ldots, SC \ and \ sc_2 = 1, \ldots, SC \quad (13)$$

The objective function of the manufacturer's models is the minimization of the expected inventory carrying, expected subcontracting and expected immediate subcontracting costs.

(1) and (4), Inventory Balance constraints, imply the actual replenishment amount of buyer b in period (t+j) under scenario sc_b, $f_0b(t+j, sc_b)$ should be satisfied totally, by the actual release amount in period (t+j) under scenario sc_b, $r_0b(t+j, sc_b)$.

(2) and (5), Incremental Revision constraints, imply the estimated release amount for future period (t+j) can not be revised upward by a fraction of more than $\alpha_{j+1}{}^{m}$ or downward by more than $\omega_{j+1}{}^{m}$ of the estimated release amount determined in the previous period (t+j-1), $r_{j+1}b(t-1)$.

(3) and (6), Cumulative Flexibility constraints, imply the estimated release amount for period (t+j) determined in the current period t, $r_j b(t)$, suggests bounds on the decision for the actual release amount for period (t+j) under scenario sc_b, $r_0 b(t+j, sc_b)$.

(7) Inventory Pooling constraints, imply inventory carrying decisions in scenario sc_1 and sc_2 resulting from the satisfaction of the actual replenishment amounts in scenario sc_1 and sc_2 are served by the total pooled inventory from which the required amounts can be released separately.

(8), (9), and (10) Capacity Limitation constraint, imply the sum of the actual release amounts in period (t+j) under the combination of scenario sc_1 and sc_2 can not exceed the capacity limit. We have a costly option to each of the given constant capacity limit for later periods. Due to the one period lead time subcontracting, the order given in the period t won't be on hand until period (t+1).

(11), and (12), Nonanticipativity constraints of the manufacturer, imply scenarios having a common history have the same set of inventory carrying and pooling decisions for buyer b to inherit from.

(13), Nonanticipativity constraints for subcontracting decision for period (t+1), imply the subcontracting decision for the delivery in period (t+1), $sub(t+j, sc_1, sc_2)$, should be the same under all combinations of the scenarios sc_1 and sc_2, since the order should be given in period t to have delivered in period (t+1).

INTEGRATED SUPPLY CHAIN ENVIRONMENT

An integrated supply chain model, where there is no information asymmetry between the supply chain actors is constructed. That is to say, in the integrated SC model, all information about the market demand, intended future replenishment decisions of the buyers are passed on to the manufacturer, so are the information of intended future release and subcontracting decisions of the manufacturer to the buyers. The reason to analyze this case is to see the impacts of the information sharing on the individual and system wide performance.

For the integrated supply chain model, the scenario trees constructed separately for each buyer are combined. The random occurrences in integrated SC model are only at the buyer-market interface. The buyers determine their scenario based decisions such as actual replenishment amounts, amount of ending inventory and backordered demand for each period by taking th**e** scenario trees of each one into account. According to the actual and intended future replenishment amount decisions of the periods in a given scenario, which are determined by the buyers; the manufacturer prepares his actual and intended future release amounts, respectively. Moreover, he determines his amount of ending inventory, inventory pooled and order to be given to the subcontractor for each period given a scenario.

Integrated Supply Chain Stochastic Model (INTSC-STOCH):

Finally, the integrated supply chain model can be illustrated as below;

$$\text{Min} \quad \sum_{b=1}^{2}\sum_{sc_b=1}^{SC}\sum_{j=0}^{T-1} probb(sc_b)[hb \times invb(t+j,sc_b) + bb \times backb(t+j,sc_b)] +$$

$$\sum_{b=1}^{2}\sum_{sc_b}^{SC}\sum_{j=0}^{T-1} probsb(sc_b)[hm \times invmb(t+j,sc_b)] +$$

$$\sum_{sc_1}^{SC}\sum_{sc_2}^{SC}\sum_{j=1}^{T-1} probs1(sc_1)\,probs2(sc_2)[sm \times sub(t+j, sc_1, sc_2)] +$$

$$\sum_{b=1}^{2} subex \times sub\exp b$$

s.t.

Equations (1), (2), (3), and (4) in the formulations of BUY-STOCH$_1$ and BUY-STOCH$_2$.

Equations (2), (3), (5), (6), (7), (8), (9), (10), (11), (12), and (13) in the formulation of MAN-STOCH.

$$invm1(t+j, sc_1) = invmp1(t+j-1, sc_1) + sub\exp 1 + r_0 1(t+j, sc_1) - f_0 1(t+j, sc_1)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_1 = 1, \ldots, SC \qquad (1)$$

$$invm2(t+j, sc_2) = invmp2(t+j-1, sc_2) + sub\exp 2 + r_0 2(t+j, sc_2) - f_0 2(t+j, sc_2)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_2 = 1, \ldots, SC \qquad (2)$$

The objective function of the integrated SC model is the minimization of the expected aggregate inventory carrying and backordering costs of buyers; expected inventory carrying, subcontracting and immediate subcontracting costs of manufacturer.

(1) and (2), Inventory Balance constraints of the manufacturer for buyer b, imply the actual replenishment amount of buyer b in period (t+j) under scenario sc$_b$, $f_0 b(t+j, sc_b)$ should be satisfied totally, by the actual release amount in period (t+j) under scenario sc$_b$, $r_0 b(t+j, sc_b)$. In these constraints, $f_0 b(t, sc_b)$ is the actual replenishment amount under scenario sc$_b$ and $f_0 b(t+j, sc_b)$ is the intended future replenishment amount determined by buyer b, for period (t+j) under scenario sc$_b$.

In inventory balance constraints of BUY-STOCH$_b$, $M_0b(t+j,sc_b)$'s are the random occurrences of market demand of the buyers under scenario sc_b, and of MAN-STOCH, $f_0b(t+j,sc_b)$'s are the random occurrences of the actual replenishment amounts of the buyers under scenario sc_b. However, in the INTSC-STOCH, since $f_0b(t+j,sc_b)$'s become a common decision for both parties, each buyer faces the actual market demand, and the manufacturer faces the determined actual replenishment amounts in different scenarios. That is, the manufacturer doesn't face random occurrences of the replenishment amounts.

CHAPTER IV

TWO-STAGE STOCHASTIC MODELLING AND SOLUTION METHOD

The two-stage stochastic programming is chosen as a technique for formulation, since the decision variables of the problem can be partitioned into two sets. The first-stage variables correspond to the decisions that need to be made prior to realization of uncertain demand, are here and now decisions. The replenishment amount estimates, for the buyers and the estimated release amounts, for the manufacturer, which are independent of random occurrences and are determined prior to demand realizations of uncertain demand, are the first stage variables. Subsequently, based on these estimated replenishment and release decisions and a given realization of the random demand the second-stage decisions are made wait and see decisions. That is to say, the actual replenishment and release amounts are decided in accordance with the values of the first stage variables.

The presence of uncertainty is translated into the stochastic nature of the costs associated with the second-stage decisions. Therefore, the objective function consists of the sum of the first-stage decision costs and the expected second-stage recourse costs. Since all inventory carrying, backordering, actual replenishment, actual release and subcontracting decision variables are made accordance with a random realization, they are “wait and see” decision variables. Thus, in all two-stage stochastic programming models for the SC actors, there exist no first stage costs. This means that both the buyers and the manufacturer are free in their decisions in the estimates. However, these estimates put bounds on the wait and see decisions, the actual replenishment and actual release amounts, and so affect the capacity and subcontracting decisions.

This chapter is organized as follows. In $3.1, the structure of a two-stage stochastic programming model is introduced. Then, the two-stage stochastic models for the buyers, the manufacturer, and the integrated supply chain are presented. In $3.2, the applications of Benders decomposition algorithm for the models presented in the previous section are displayed.

4.1 TWO STAGE STOCHASTIC MODELS AND BENDERS DECOMPOSITION

The two-stage stochastic programming model for the buyer b can be presented as follows;

Min Q

$$Q = E_{[\mu_0(t),\mu_0(t+1),\ldots\mu_0(t+T-1)],,}\left[\begin{array}{l} \min \sum_{j=1}^{T-1} hb \times invb(t+j) + bb \times backb(t+j) \\ s.t. \\ invb(t+j) - backb(t+j) = \\ invb(t+j-1) - backb(t+j-1) + f_0 b(t+j) - \mu_0 b(t+j) \\ \quad \forall j = 0,\ldots,T-1 \\ (1-\Omega_j^b) f_j b(t) \le f_0 b(t+j) \le (1+\mathrm{A}_j^b) f_j b(t) \\ \quad \forall j = 0,\ldots,T-1 \\ \end{array}\right]$$

s.t.

$$(1-\omega_{j+1}^{b})f_{j+1}b(t-1) \le f_{j}b(t) \le (1+\alpha_{j+1}^{b})f_{j+1}b(t-1)$$

$$\forall j = 0,\ldots,T-2$$

The outer problem consists of the first stage variables, that is, the estimated replenishment amounts, $f_jb(t)$'s. The inner problem is the recourse function which is comprised of the second stage variables, that is, the scenario dependent variables. It is the recourse paid to the overall problem due to the uncertainty. The interaction between the outer and inner problems takes place through the incremental flexibility constraints. Our aim is to obtain a closed form for Q (recourse function) in terms of the first stage variables. This is achieved by solving the inner recourse problem followed by analytical expectation evaluation. The approach is similar to all other problems, i.e., problems of the manufacturer and the integrated SC.

The main challenge associated with solving two-stage stochastic problems is the evaluation of the expectation of the inner recourse problem. For the scenario-based representation of uncertainty, this can be achieved by explicitly associating a second-stage variable with each scenario and solving the large-scale formulation by efficient solution techniques such as Dantzig-Wolfe decomposition and Benders decomposition.

The stochastic programming model is difficult to solve since the number of variables and constraints can obviously become very large as the number of scenarios grows. The number of scenarios, in turn, grows exponentially in terms of the sample space for random demands. Benders decomposition has been used in stochastic programming as a method for breaking the model down into small components that can be analyzed separately. Not only due to this feature of Benders decomposition, but also in order to incorporate the stochastic terms through expectations by obtaining the closed form of the recourse function, Benders Decomposition Algorithm is used to solve the stochastic programming models for SC actors and the integrated supply chain.

In the decomposition algorithm, the stochastic supply chain planning model is solved iteratively through a sequence of LP sub problems and LP master problems, with the former minimizing the objective that provides upper bounds (UB) to the expected total cost. Since some decision variables are taken as given to the sub problem, it supplies upper bound for the overall problem. The latter providing lower bounds (LB), minimizes the maximum cut, i.e., LB. The cuts are generated by sum of the expected total cost suggested by the sub problem and the dualized costs at each iteration. The dualized costs where the master problem decision variables exist gives the LB character since it represents the possible reduction from the expected total cost.

We partition the stochastic LP problem according to the first and second decision stages stated in the introduction part of this chapter. In the master problem, the estimated replenishment and release amounts are determined, and then in the sub problem, the decisions for the actual replenishment by the buyers and release amounts by the manufacturer, inventory carried, amount backordered and amount subcontracted are decided. For instance for the first buyer, the master problem includes all estimated replenishment decisions, $f_j b(t)$'s which are in fact the "here and now" decisions determined prior to a realization of the random demand. The sub problem involves the remaining scenario based decisions; which are actual replenishment amounts, $f_0 b(t+j, sc_b)$, amount of ending inventory, $invb(t+j, sc_b)$

and amount backordered, $backb(t+j,sc_b)$. That is, the sub problem includes the "wait and see" decisions which are determined after the realization of the random demand and according to the predetermined master problem decisions. The sub and master problems are identical for both buyers.

However, for the manufacturer, the sub problem consists of the scenario based decisions, i.e. "wait and see" decisions, which are not only actual release amounts, $r_0b(t+j,sc_b)$, inventory carried, $invmb(t+j,sc_b)$, inventory pooled, $invmpb(t+j,sc_b)$, but also includes amount to be ordered from the one period lead time subcontractor, $sub(t+j,sc_1,sc_2)$ and the same from the immediate subcontractor, $sub\exp b$. The master model produces the "here and now" decisions, which are the estimated release decisions, $r_jb(t)$ to serve each buyer.

From the buyer's point of view, the purpose of the master problem is to find the optimal estimated replenishment decisions, to minimize the expected total cost transferred from the sub problem prior to the realization of the random demand. The purpose of the sub problem is to act upon the master problem suggestions, i.e., estimated replenishment amounts of the future periods. This is done by evaluating the expected total cost under the individual scenarios that might occur and determine the "wait and see" decisions under each scenario. For the manufacturer, the master problem aims to find the optimal estimated release amounts that will be conveyed on to the sub problem. Then, the sub problem analyzes the suggestions of the master problem upon taking all possible scenarios individually each being aggregated over the buyers.

Buyer's Two-Stage Stochastic Model:

Given any buyer, $f_j b(t)^N$ of the master problem decisions in iteration N of the decomposition algorithm are passed from the master problem to the sub problem. The sub problem and master problem at iteration N can be stated as follows;

- SUB PROBLEM

Min $$\sum_{sc_b=1}^{SC}\sum_{j=0}^{T-1} probb(sc_b)[hb \times invb(t+j, sc_b) + bb \times backb(t+j, sc_b)]$$

s.t.

$$invb(t+j, sc_b) - backb(t+j, sc_b) =$$
$$invb(t+j-1, sc_b) - backb(t+j-1, sc_b) + f_0 b(t+j, sc_b) - M_0 b(t+j, sc_b)$$

$$\forall j = 0, \ldots, T-1 \ and \ \forall sc_b = 1, \ldots, SC \quad (1)$$

$$(1-\Omega_j^b) f_j b(t) \le f_0 b(t+j, sc_b) \le (1+\mathrm{A}_j^b) f_j b(t)$$

$$\forall j = 0, \ldots, T-1 \ and \ \forall sc_b = 1, \ldots, SC \quad (2)$$

$$invb(t+j, {sc_b}^{l,k}) = invb(t+j, {sc'}_b^{l,k})$$

$$\forall j = 0, \ldots, T-1 \ and \ \forall {sc_b}^{l,k} = 1, \ldots, SC \quad (3)$$

The objective function of the sub problem of the buyers is the minimization of the expected inventory carrying and backordering costs over the scenarios.

(2) Cumulative Flexibility constraints imply the estimated replenishment amount for period (t+j) determined in the master problem, $f_j b(t)$, impose bounds on the decision for the actual replenishment amount for period (t+j) under any scenario sc_b, $f_0 b(t+j, sc_b)$.

(1) and (3) are the same as the equations (1) and (4) in BUY-STOCH$_b$ described in the previous chapter, respectively.

- MASTER PROBLEM

Min M

s.t.

$$(1-\omega_{j+1}^{b})f_{j+1}b(t-1) \le f_j b(t) \le (1+\alpha_{j+1}^{b})f_{j+1}b(t-1) \quad \forall j = 0,\ldots,T-2 \qquad (4)$$

$$\begin{aligned} M \ge & \sum_{sc=1}^{SC}\sum_{j=0}^{T-1} probb(sc_b)\left[hb\times(invb(t+j,sc_b))^N + bb\times(backb(t+j,sc_b))^N\right] + \\ & \sum_{j=1}^{T-2}\sum_{sc_b=1}^{SC}\rho U_{sc_b}^{b}(t+j)^N[(1+\mathrm{A}_j^b)f_j b(t) - f_0 b(t+j,sc_b)^N] + \\ & \sum_{j=1}^{T-2}\sum_{sc_b=1}^{SC}\rho L_{sc_b}^{b}(t+j)^N[f_0 b(t+j,sc_b)^N - (1-\Omega_j^b)f_j b(t)] \end{aligned} \qquad (5)$$

The objective function of the master problem of the buyers is the minimization of the maximum cut generated in the sub problem.

(4) is the same as equation (2) in BUY-STOCH$_b$.

In (5), $\rho U_{sc_b}^{b}(t+j)^N$ and $\rho L_{sc_b}^{b}(t+j)^N$'s are the dual multipliers of the cumulative flexibility constraints (2) in the sub problem; i.e., of the upper and lower bounds for the intended future replenishment amounts; $f_0 b(t+j,sc_b) \le (1+\mathrm{A}_j^b)f_j b(t)$ and $(1-\Omega_j^b)f_j b(t) \le f_0 b(t+j,sc_b)$, respectively and $f_0 b(t+j,sc_b)^N$, $invb(t+j,sc_b)^N$ and $backb(t+j,sc_b)^N$ are the given optimal values of the sub problem at iteration N. The master decision variables, which are the estimated replenishment amounts for period (t+j), $f_j b(t)$'s, appear in the incremental revision constraints (4) and second part of (5).

Constraint (5) is the so-called Benders cut, and can be considered as an aggregate representation of all scenarios on the total cost suggested by the sub problem decision variables in iteration N. At the beginning, there are no cuts in the master problem, and then they are sequentially added one by one after solving a sub problem in each iteration. The second buyer has an identical formulation.

<u>Manufacturer's Two-Stage Stochastic Model:</u>

The manufacturer faces two different random occurrences of actual replenishment in all the periods. He is informed only of the current period's actual replenishment amounts by the buyers through their orders. For other periods, he has his own inferences on the replenishments concerning the two buyers. The $r_j b(t)^N$'s for buyer b determined in the master problem in iteration N is transferred to the sub problem. The sub problem and master problem of the manufacturer at the iteration N is presented as follows.

- SUB PROBLEM

Min $$\sum_{b=1}^{2}\sum_{sc_b}^{SC}\sum_{j=0}^{T-1} probsb(sc_b)[hm \times invmb(t+j, sc_b)] +$$

$$\sum_{sc_1}^{SC}\sum_{sc_2}^{SC}\sum_{j=1}^{T-1} probs1(sc_1)probs2(sc_2)[sm \times sub(t+j, sc_1, sc_2)] +$$

$$\sum_{b=1}^{2} subex \times sub\exp b$$

s.t.

$$invm1(t+j, sc_1) = invmp1(t+j-1, sc_1) + sub\exp 1 + r_0 1(t+j, sc_1) - f_0 1(t+j, sc_1)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_1 = 1, \ldots, SC \tag{1}$$

$$(1-\Omega_j^{m1})r_j 1(t) \le r_0 1(t+j, sc_1) \le (1+\mathrm{A}_j^{m1})r_j 1(t)$$

$$\forall j = 0, \ldots, T-1 \;\; and \; sc_1 = 1, \ldots, SC \tag{2}$$

$$invm2(t+j, sc_2) = invmp2(t+j-1, sc_2) + sub\exp 2 + r_0 2(t+j, sc_2) - f_0 2(t+j, sc_2)$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{3}$$

$$(1-\Omega_j^{m2})r_j 2(t) \le r_0 2(t+j, sc_2) \le (1+\mathrm{A}_j^{m2})r_j 2(t)$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{4}$$

$$invm1(t+j, sc_1) + invm2(t+j, sc_2) = invmp1(t+j, sc_1) + invmp2(t+j, sc_2)$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ sc_1 = 1,\ldots,SC \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{5}$$

$$r01(t, sc_1) + r02(t, sc_2) \le cap(t, sc_1, sc_2) + SUB(t)$$

$$sc_1 = 1,\ldots,SC \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{6}$$

$$r01(t+j, sc_1) + r02(t+j, sc_2) \le cap(t+j, sc_1, sc_2) + sub(t+j, sc_1, sc_2)$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ sc_1 = 1,\ldots,SC \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{7}$$

$$cap(t+j, sc_1, sc_2) \le CAP$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ sc_1 = 1,\ldots,SC \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{8}$$

$$invmb(t+j, sc_b^{\ l,k}) = invmb(t+j, sc_b'^{\,l,k})$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ \forall b = 1,2 \ \textit{and}\ \forall sc_1^{\ l,k} = 1,\ldots,SC \tag{9}$$

$$invmpb(t+j, sc_b^{\ l,k}) = invmpb(t+j, sc_b'^{\,l,k})$$

$$\forall j = 0,\ldots,T-1 \ \textit{and}\ \forall b = 1,2 \ \textit{and}\ \forall sc_1^{\ l,k} = 1,\ldots,SC \tag{10}$$

$$sub(t+1, sc_1, sc_2) = sub(t+1, sc_1', sc_2') \qquad \forall sc_1 = 1,\ldots,SC \ \textit{and}\ sc_2 = 1,\ldots,SC \tag{11}$$

The objective function of the sub problem for the manufacturer is the minimization of the expected inventory carrying, subcontracting and immediate subcontracting costs over the scenarios.

(2) and (4), Cumulative Flexibility constraints imply the estimated release amount for period (t+j) determined in master problem, $r_j b(t)$, impose bounds on the decision for the actual release amount under any scenario sc_b, $r_0 b(t+j, sc_b)$.

Other constraints, (1), (3), (5), (6), (7), (8), (9), (10), (11) are the same as the equations (1), (4), (7), (8), (9), (10), (11), (12), and (13) explained in MANUF-STOCH in the previous chapter, respectively.

- MASTER PROBLEM

Min $\quad M$

s.t.

$$(1-\omega_{j+1}^{m1})r_{j+1}1(t-1) \le r_j 1(t) \le (1+\alpha_{j+1}^{m1})r_{j+1}1(t-1) \quad for\, j = 0,\ldots,T-1 \tag{12}$$

$$(1-\omega_{j+1}^{m2})r_{j+1}2(t-1) \le r_j 2(t) \le (1+\alpha_{j+1}^{m2})r_{j+1}2(t-1) \quad for\, j = 0,\ldots,T-1 \tag{13}$$

$$\begin{aligned} M \ge \; & \sum_{b=1}^{2}\sum_{sc=1}^{SC}\sum_{j=0}^{T-1} probsb(sc_b)\left[hm \times (invmb(t+j,sc_b))^N\right] + \\ & \sum_{sc_1=1}^{SC}\sum_{sc_2=1}^{SC}\sum_{j=1}^{T-1} probs1(sc_1)probs2(sc_2)\left[sm \times (sub(t+j,sc_1,sc_2))^N\right] + \\ & \sum_{b=1}^{2} subex \times sub\exp b^N + \\ & \sum_{j=1}^{T-2}\sum_{sc_1=1}^{SC} \rho U_{sc_1}^{m1}(t+j)^N[(1+\mathrm{A}_j^{m1})r_j 1(t) - r_0 1(t+j,sc_1)^N] + \\ & \sum_{j=1}^{T-2}\sum_{sc_1=1}^{SC} \rho L_{sc_1}^{m1}(t+j)^N[r_0 1(t+j,sc_1)^N - (1-\Omega_j^{m1})r_j 1(t)] + \\ & \sum_{j=1}^{T-2}\sum_{sc_2=1}^{SC} \rho U_{sc_2}^{m2}(t+j)^N[(1+\mathrm{A}_j^{m2})r_j 2(t) - r_0 2(t+j,sc_2)^N] + \\ & \sum_{j=1}^{T-2}\sum_{sc_2=1}^{SC} \rho L_{sc_2}^{m2}(t+j)^N[r_0 2(t+j,sc_2)^N - (1-\Omega_j^{m2})r_j 2(t)] \end{aligned} \tag{14}$$

The objective function of the master problem of the manufacturer is the minimization of the maximum cut generated in the sub problem.

(12) and (13) are the same equations (2) and (5) in the MANUF-STOCH presented in the previous chapter, respectively.

In (14), $\rho U_{sc_1}^{m1}(t+j)^N$ and $\rho L_{sc_1}^{m1}(t+j)^N$'s are the dual multipliers of the cumulative flexibility constraints for the first buyer (2) in the sub problem at iteration N, i.e., of the upper and lower bounds for intended future release amounts $r_0 1(t+j, sc_1) \le (1+\mathrm{A}_j^{m1}) r_j 1(t)$ and $(1-\Omega_j^{m1}) r_j 1(t) \le r_0 1(t+j, sc_1)$, respectively. Also, $\rho U_{sc_2}^{m2}(t+j)^N$ and $\rho L_{sc_2}^{m2}(t+j)^N$'s are the dual multipliers of the cumulative flexibility constraints for the second buyer (4) in the sub problem at iteration N, i.e., of the constraints $r_0 2(t+j, sc_2) \le (1+\mathrm{A}_j^{m2}) r_j 2(t)$ and $(1-\Omega_j^{m2}) r_j 2(t) \le r_0 2(t+j, sc_2)$, respectively.

$r_0 1(t+j, sc_1)^N$, $r_0 2(t+j, sc_2)^N$, $invmb(t+j, sc_b)^N$, $sub(t+j, sc_1, sc_2)^N$, and $sub\exp b^N$ are the given optimal values of the sub problem at iteration N. The master problem decision variables, $r_j b(t)$'s, appear in the incremental revision constraints (12), (13) and the second part of (14).

Constraint (14) is the Benders cut, which is sequentially added one by one after solving a sub problem in each iteration.

Integrated Supply Chain Two-Stage Stochastic Model

Finally, the formulation of the sub and master problems for the integrated supply chain model can be illustrated as in the following;

- SUB PROBLEM

$$\text{Min} \quad \sum_{b=1}^{2} \sum_{sc_b=1}^{SC} \sum_{j=0}^{T-1} probb(sc_b)[hb \times invb(t+j, sc_b) + bb \times backb(t+j, sc_b)] +$$

$$\sum_{b=1}^{2} \sum_{sc_b}^{SC} \sum_{j=0}^{T-1} probsb(sc_b)[hm \times invmb(t+j, sc_b)] +$$

$$\sum_{sc_1}^{SC}\sum_{sc_2}^{SC}\sum_{j=1}^{T-1} probs1(sc_1)probs2(sc_2)[sm \times sub(t+j, sc_1, sc_2)] +$$

$$\sum_{b=1}^{2} subex \times sub\exp b$$

s.t

Equations (1), (2), and (3) in the sub problems of each buyer

Equations (2), (3), (4), (6), (7), (8), (9), (10), and (11) in the sub problem of the manufacturer

$$invm1(t+j, sc_1) = invmp1(t+j-1, sc_1) + sub\exp 1 + r_0 1(t+j, sc_1) - f_0 1(t+j, sc_1)$$

$$\forall j = 0, \ldots, T-1 \ and \ sc_1 = 1, \ldots, SC \qquad (1)$$

$$invm2(t+j, sc_2) = invmp2(t+j-1, sc_2) + sub\exp 2 + r_0 2(t+j, sc_2) - f_0 2(t+j, sc_2)$$

$$\forall j = 0, \ldots, T-1 \ and \ sc_2 = 1, \ldots, SC \qquad (2)$$

The objective function of the integrated supply chain model is the combination of the objective function in the buyers' and manufacturer's sub problems.

(1) and (2), Inventory Balance constraints of the manufacturer for buyer b imply the actual replenishment amount of buyer b in period (t+j) under scenario sc_b should be satisfied totally, by the actual release amount in period (t+j) under scenario sc_b, $r_0b(t+j, sc_b)$. In these constraints, $f_0b(t, sc_b)$ is the actual replenishment amount under scenario sc_b and $f_0b(t+j, sc_b)$ is the intended future replenishment amount determined by buyer b, for period (t+j) under scenario sc_b.

- MASTER PROBLEM

Min M

s.t.

Equations (4) in the master problems of each buyer

Equations (12) and (13) in the master problem of the manufacturer

$$
\begin{aligned}
M \geq \; & \sum_{b=1}^{2}\sum_{sc=1}^{SC}\sum_{j=0}^{T-1} probb(sc_b)\left[hb(invb(t+j,sc_b))^N + bb\times(backb(t+j,sc_b))^N\right]+ \\
& \sum_{b=1}^{2}\sum_{sc=1}^{SC}\sum_{j=0}^{T-1} probsb(sc_b)\left[hm\times(invmb(t+j,sc_b))^N\right]+ \\
& \sum_{sc_1=1}^{SC}\sum_{sc_2=1}^{SC}\sum_{j=1}^{T-1} probs1(sc_1)\,probs2(sc_2)\left[sm\times(sub(t+j,sc_1,sc_2))^N\right]+ \\
& \sum_{b=1}^{2} subex\times sub\exp b^N + \\
& \sum_{b=1}^{2}\left\{\sum_{j=1}^{T-2}\sum_{sc_b=1}^{SC}\rho U_{sc_b}^{b}(t+j)^N[(1+\mathrm{A}_j^b)f_j b(t) - f_0 b(t+j,sc_b)^N]+\right. \\
& \left.\sum_{j=1}^{T-2}\sum_{sc_b=1}^{SC}\rho L_{sc_b}^{b}(t+j)^N[f_0 b(t+j,sc_b)^N - (1-\Omega_j^b)f_j b(t)]\right\}+ \\
& \sum_{b=1}^{2}\left\{\sum_{j=1}^{T-2}\sum_{sc_b=1}^{SC}\rho U_{sc_b}^{mb}(t+j)^N[(1+\mathrm{A}_j^{mb})r_j b(t) - r_0 b(t+j,sc_b)^N]+\right. \\
& \left.\sum_{j=1}^{T-2}\sum_{sc_{b1}=1}^{SC}\rho L_{sc_b}^{mb}(t+j)^N[r_0 b(t+j,sc_b)^N - (1-\Omega_j^{mb})r_j b(t)]\right\} \qquad (3)
\end{aligned}
$$

The objective function of the master problem of the integrated supply chain is the minimization of the maximum cut generated in the sub problem.

In (3), $\rho U_{sc_b}^{b}(t+j)^N$, $\rho L_{sc_b}^{b}(t+j)^N$ and $\rho U_{sc_b}^{mb}(t+j)^N$, $\rho L_{sc_b}^{mb}(t+j)^N$'s are the dual multipliers of the cumulative flexibility constraints of each buyer and of the manufacturer for each buyer in their sub problems, $f_0 b(t+j,sc_b)^N$ and, $r_0 b(t+j,sc_b)^N$, $invb(t+j,sc_b)^N$, $backb(t+j,sc_b)^N$, $invmb(t+j,sc_b)^N$,

$sub(t+j, sc_1, sc_2)^N$, and $sub\exp b^N$ are the given optimal values of the sub problem at iteration N.

Constraint (3) is the Benders cut which is consecutively added one by one after solving a sub problem in each iteration.

4.2 BENDERS DECOMPOSITION ALGORITHM

Our main interest is to solve the two-sage stochastic programming models. Thus, we utilize Benders Decomposition algorithm, where the stochastic model is solved iteratively through a sequence of LP sub problems and LP master problems and which guarantees convergence.

The algorithm for the buyers can be presented as follows;

Step 1 Set N to 1. Select $f_1 b(t)^N$ from WCP. Set UB= +infinity and LB= -infinity

Step 2 Solve Sub Problem(N)

Step 2.1 Update the upper bound by setting UB=min{UB, expected total cost^N}

Step 3 Solve the Master Problem(N) to determine $f_1 b(t)^{N+1}$ and a lower bound to total cost. Set LB equal to the solution of this Master Problem(N)

Step 4 If UB-LB < tolerance, stop. Otherwise, set N=N+1, and go to Step 2.

In Benders decomposition algorithm for the manufacturer, $f_1 b(t)^N$ is replaced by $r_1 b(t)^N$ which is found by solving WCP of the manufacturer. The expected total cost at iteration N is comprised of the $r_0 b(t+j, sc_b)^N$,

$invmb(t+j,sc_b)^N$, $invmpb(t+j,sc_b)^N$ and $sub(t+j,sc_1,sc_2)^N$. The steps to follow are the same as in the buyer's case.

In step 1 of both algorithm applications, the initial values, $f_j b(t)^1$ and $r_j b(t)^1$ can be obtained by solving, what we called "the worst case problem" (WCP). WCP is acquired by replacing each random market demand and each random replenishment amount by its worst scenario, that is, by the largest amount of possible demand and replenishment values of each period. By this way, the estimated replenishment and release amounts are initially determined as if the biggest value of the demand or replenishment is realized, respectively.

At the beginning, the WCP is selected to employ for the manufacturer in order not to generate such estimated release amounts that will be short of satisfying the total actual replenishment amounts for the two buyers. That is, not to get into infeasibility in inventory balance constraints of the manufacturer for the buyers individually in the sub problem. Although, there is no possibility to get into infeasibility in inventory balance constraints of the two buyers due to allowing for backorders, to be consistent for all the SC actors, the WCP is employed also in the buyer's case.

The Benders decomposition algorithm for the buyers can be illustrated in Figure 4.1. First by the worst case problem (WCP), the initial optimal estimated replenishment amounts are determined. Then, they are input to the sub problem. After taking the suggestions of the WCP into consideration, the sub problem determines the actual replenishment amounts, inventory carrying and backordering amounts in expected value terms, considering all scenarios. The expected total cost found in each optimization of the sub problem supplies a new upper bound (UB) for the overall problem. The new UB found at each iteration should be less than or equal to the UB found at the previous iteration. This is due not to make an iteration which is not close to the optimal solution with respect to the solution of the previous iteration and to reduce the gap between the UB and LB more efficiently. Afterwards, the expected total cost, and the most recent optimal values of the sub problem decisions are transferred to the master problem. New optimal estimated replenishment amounts are determined in the master problem, where the optimal objective function value establishes a lower bound (LB) for the overall problem. The main problem takes all previously generated LB's into account. Since a new cut is added to the master problem at each iteration, the new LB is found on minimizing the maximum cut, i.e., LB. Thus, the algorithm tightens the lower bounds iteratively. When the gap between UB and LB is less than a predetermined tolerance (0.0001), the problem is said to be solved with sufficient accuracy.

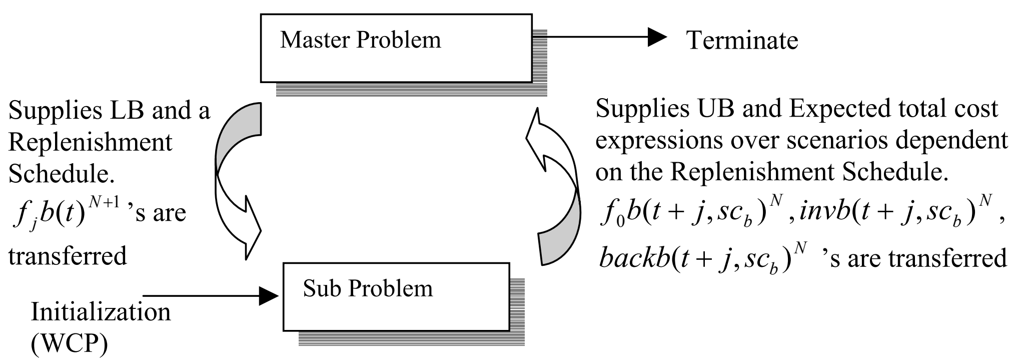

Figure 4.1 Benders Decomposition Algorithm

The figure of the algorithm for the manufacturer is not presented, since it has the same approach with the buyers'.

The Benders cut stated above assumes that all sub problems are feasible. However, the trial points generated by the master problem may not necessarily be feasible for all realizations of the random parameters. An approach appropriate for this supply chain planning problem, which is adding feasibility constraints to the master problem, is taken into account for implementation.

The feasibility constraints for the buyers are presented below.

$$(1-\Omega_j^b) f_j b(t)^{N+1} \leq f_0 b(t+j, sc_b)^N \leq (1+\mathrm{A}_j^b) f_j b(t)^{N+1}$$

$$\forall j = 1,\ldots,T-2 \;\; and \; sc_b = 1,\ldots,SC \qquad (1)$$

For the buyer's case, the above formulation implies the new optimal estimated replenishment amounts generated by the master problem at iteration N; construct such bounds that they should cover at least the actual replenishment amount values in any scenario sc_b predetermined in the sub problem at iteration N.

For the manufacturer's case, only the estimated replenishment and predetermined actual replenishment amounts are replaced by estimated release and predetermined actual release amounts, respectively.

Although the loop terminates due to the achievement of satisfactory convergence, the estimated replenishment and estimated release amounts can take such values that they can make the sub problem infeasible. By the feasibility constraints presented above, the stated case is prevented.

In our analysis, specifically, given the capacity limit and the release schedule of the first buyer, after introducing the second buyer, the capacity planning issue of the manufacturer and the effect of the contract parameters specified by the second buyer herself are tried to be examined.

In this study, we try to address the objectives; to provide a structure for the analysis of quantity flexibility contracts, with the assumption of stationary and uncertain market demand that seeks the challenge for flexibility; suggest forecasting and ordering policies, for buyers who are obliged to purchase a certain amount of their estimates, for manufacturer who guarantees to provide a certain amount of the buyer's replenishment amounts; and link these behaviors to individual and system wide performance, so guide the negotiation of contracts.

CHAPTER V

EXPERIMENT

This study is based mainly on the incentives of the second buyer who is offered a QF contract by a manufacturer, and the incentives of the manufacturer offering a QF contract to the second buyer while he has an active QF contract with another buyer.

We try to analyze the causes and effects for the attitudes of the Supply Chain (SC) actors individually and their attitudes in the integrated supply chain with the environment forming these attitudes. We intend to find out answers to some research questions such as how much flexibility the manufacturer can tolerate without any increase in costs, how the choice of flexibility is affected by demand variability, and how much the manufacturer's own capacity is utilized in the presence of prior commitments.

This chapter states why demand variation, flexibility tightness and cost are selected as the three main factors, and how the levels and the values for these levels are effective. In $5.1, the definition of the factors for the analysis and their determined levels are presented. In $5.2, the approach taken for data generation is displayed. In $5.3, how the samples for the full factorial experiment are created is stated. Finally, in $5.4, an example for the General Algebraic Modeling Systems

(GAMS) utilization and the application of Benders Decomposition algorithm are presented.

5.1 EXPERIMENTAL FACTORS

In order to carry out our analysis for the effect of a QF contract, its usage, its options offered to all the parties in the supply chain environment, the individual and systemwide attitudes of SC actors, we construct a full factorial experiment. For the experiment, three factors are specified, which are demand variation, flexibility tightness requested and offered, and cost rates. By the full factorial experiment, we try to discover all causes and effects of the events established by changing all possible levels of the experimental factors determined.

The demand variation is selected as a factor to experiment with in order to examine the effect of variation on the usage of quantity flexibility option. The option of quantity flexibility means whether the SC actor takes advantage of the upward or downward flexibility. In other words, when a larger amount of demand than expected occurs, the buyer can replenish up to her upper bound set by her estimation in the previous period. When the opposite occurs, she can replenish less than her estimation made similarly.

The experimental factor, demand variation (DEVAR), is defined as the coefficient of variation of the discrete demand values that can occur in a period. The coefficient of variation is a way to express the variation as a fraction of the mean. It is useful when comparing variability of two or more data sets that differ considerably in their observations.

We try two levels which are medium and high variation based on the coefficient of variation. In our full factorial experiment, we aim to analyze at which amount the flexibility option is required or at which amount the effect of flexibility is effective in different situations with the factor, DEVAR, set at levels medium or high. Moreover, the distribution of the benefits among the SC actors in the decentralized and centralized environments, and the system wide performance at different levels of demand variation are examined.

Flexibility tightness (FLEX) is chosen as the second factor. Flexibility tightness is defined by rigidity of the flexibility offered or requested. The tightness of flexibility has two levels namely tight and loose flexibility. By the selection of the flexibility tightness as a factor, we intend to analyze the attitudes of the SC actors in the individual and in the integrated SC environments. Especially, in the integrated SC, when the tightness of flexibility is changed for a party, whether the option provides an overall benefit only to that party or to other parties is investigated. We also try to examine the usage of flexibility when the actors face with different demand values. For instance, when the buyer faces a high demand, her attitude when she is given a tight or loose flexibility option and the reason of her attitude are questioned. For the first case, where the flexibility parameters are determined by the second buyer; the first buyer and the manufacturer have their own set of defined flexibility parameters. The flexibility of the first buyer can be tight or loose and those of the manufacturer can as well be tight or loose. Taking the combinations of the two parties into account, this factor has four levels for the analysis. In the second case where the manufacturer determines his quantity flexibility parameters for the second buyer, the first buyer is given the loose flexibility level determined in the first case.

Then, there will be again four combinations to examine for the second buyer and the manufacturer.

Our final factor is the cost, specifically the costs of inventory carrying, backordering, subcontracting and immediate subcontracting, (COST). This factor has two levels, which are low and high cost. In the determining the values of inventory carrying, backordering costs, etc., we intend to generate four different situations where the cost burden is transferred first on none of the parties, then only on the manufacturer, then only on the buyers, and finally, on all. That is, similar to FLEX, this factor has four combinations, which include the combination of the low and high unit cost components of the two buyers and the low and high cost of the manufacturer. The inventory carrying costs of the two buyers and the manufacturer are taken as the same. Other costs are determined relative to the inventory carrying cost taken as a base. The burden on the buyers is handled by increasing the backordering costs of the buyers. By increasing the subcontracting and immediate subcontracting costs, the manufacturer is given the burden of the cost. By the cost factor, we try to find answers to the questions; who gets the most benefit, and whether the attitudes of the SC actors differ in the individual and coordinated environments. These are studied under the conditions where the cost burden is transferred onto different parties.

5.2 DATA GENERATION

The effects of the environmental characteristics consisting of the relations between the actors, the information shared by the parties, the type of the demand they face with, the quantity flexibility parameters specified, and the cost parameters that applies are investigated. We make our experiment by taking a rolling planning horizon of 4 periods. 4 periods is appropriate for our analysis since subcontracting lead time is one period and we want to see the effects of lead time, also we aim to observe the rolling horizon fashion and the two buyers' planned inventories and their utilizations of the flexibility options provided. Our approach is to give minimum and maximum values for the factor levels such as medium and high DEVAR, tight and loose FLEX, and low and high COST. For the analysis, the two-stage stochastic models presented in the previous chapter are constructed with the specified demand variation, flexibility tightness and cost factor levels.

5.2.1 GENERATION OF FACTOR LEVELS

In order to carry out our full factorial experiment, we first define values for the levels of the experimental factors. Then, to obtain the numerical results for the specified analysis, we generate the data to be utilized in the two-stage stochastic models constructed in the previous chapter.

DEMAND VARIATION

For the factor of DEVAR, the logic is based on coefficient of variation (CV). For the levels, medium and high DEVAR, the CV values tested can be seen in the Table 5.1.

Table 5.1 Coefficient of Variation at different DEVAR levels

		DEMAND VARIATION	
		Medium	High
Period	2	0.08	0.16
	3	0.09	0.17
	4	0.10	0.18

Since the coefficient of variation represents how the values of the discrete values for the demand realization is disperse about the mean, for the medium demand variation data set, the CV values between 0.08 and 0.10 seems appropriate. In order to represent the high demand variation, we take twice the initial coefficient of variation. It is assumed that the estimations of the buyers for the market demand has an increasing trend in CV due to the increasing uncertainty as the estimated period gets apart from the current period. In other words, if the planning horizon length is 4 periods, the second, third, and fourth periods have CV's of 0.08, 0.09, and 0.10, respectively at medium DEVAR level. However, at high DEVAR level, the SC actor has 0.16, 0.17, and 0.18 values for CV of the second, third, and fourth periods, respectively.

In fact, at the beginning of our experimental study, we took the coefficient of variation as 0.31, 0.32, and 0.33 for medium level, which is a good CV to analyze the effects of the flexibility options. However, the required sample size with 0.1 error was found as 20. Since the model has a rolling horizon fashion, this sample size stands for 20*4 times running the model because one period's solution constitutes the input of the next period's problem. Therefore, we reduce the CV values and in relation reduce the flexibility parameter values. Otherwise, the estimates of the SC actors will always fall within the upper and lower bounds, and hence we can not observe the conditions where the flexibility options are used effectively and where they are inadequate.

FLEXIBILITY TIGHTNESS

For the factor FLEX, the level values are determined in such a way that they give the opportunity to all SC parties to exploit the flexibility option. They are found by performing some pilot runs, and examining the attitudes of the SC actors in the specified environment. In the tight flexibility level of the first buyer and the manufacturer, they are given the flexibilities which provide the SC actors to utilize the bounds constructed. However, in the loose flexibility level, the estimates by the actors can fall within the bounds; consequently they carry limited inventory or backorder less. We expect to see the effect of the flexibility tightness mainly at high DEVAR level.

According to the model presented in the study by Tsay and Lovejoy (1999), one of the specifications of their proposition is that the flexibility parameters of the upstream party should not be less than the flexibility parameters of the downstream parties. They showed that by the proposition, a party which has more flexibility in its supply process than it offers its customers can meet all obligations with zero inventory. They state that when the opposite occurs, the party will absorb the flexibility with no benefit to the system. Therefore, the flexibility parameters of the manufacturer for the first and second buyers are determined relative to theirs. When the second buyer determines her contract parameters, the manufacturer settles on his own flexibility parameters in the same proportion obtained by dividing the tight flexibility parameter of the manufacturer for the first buyer by the tight flexibility of the first buyer. By multiplying the obtained ratio, what we named Tight Relative Flexibility (R_T), with the flexibility parameters of the second buyer, the tight flexibility parameters of the manufacturer for the second buyer are determined. The formula of the tight relative flexibility that is given to the first buyer can be given as;

$$R_T = \frac{\text{Tight Flexibility of the Manufacturer for the First Buyer}}{\text{Tight Flexibility of the First Buyer}} \quad (1)$$

Taking the tight flexibility parameters of the first buyer as a base, we can infer reasonably the loose level of her, and in turn the tight and loose levels of the manufacturer for each buyer. All parameters need satisfying the condition that the flexibility parameters of the upstream party should not be less than those of the downstream parties. Thus, the first buyer's loose flexibility parameters are settled on same as the tight flexibility of the manufacturer. According to this, the tight and loose flexibilities of the first buyer can be seen in Table 5.2.

Table 5.2 Flexibility Parameters of the First Buyer in different FLEX levels

		FLEXIBILITY TIGHTNESS			
		tight		loose	
		ω^1	α^1	ω^1	α^1
Period	1	0.05	0.05	0.10	0.10
	2	0.06	0.06	0.11	0.11
	3	0.07	0.07	0.12	0.12

, where $\omega^1 = [\omega^1{}_1, \omega^1{}_2, \omega^1{}_3]$, and $\alpha^1 = [\alpha^1{}_1, \alpha^1{}_2, \alpha^1{}_3]$.

The tight and loose flexibility parameters of the manufacturer for the second buyer are determined differently in two cases. In the first case, at the beginning of the planning horizon, the second buyer determines her contract flexibility parameters while minimizing her total costs consisting of inventory carrying and backordering.

In this model named as BUY-DEC, the (ω^b, α^b) pair and (Ω^b, A^b) pair are also decision variables. After the determination of the flexibility parameters, she utilizes the BUY-STOCH model for her planning issues with given incremental and cumulative flexilbity parameters. That is, (ω^b, α^b) and (Ω^b, A^b) pairs become parameters in BUY-STOCH. However, when the decision maker is the manufacturer, the manufacturer solves the model what we named MAN-DEC with the objective function of maximum of the minimium incremental flexibility values while having a total cost limit. Again in this model, the flexibility parameters for the second buyer are decision variables. Then he finds the flexibility parameters for the second buyer, and accordingly, he offers the adjusted flexibility parameters to the second buyer and uses the MAN-STOCH model for his own plans. The details and the experiment related to this case will be given at the end of the flexibility tightness subsection. The model circulation and the changes of the decision variables to parameters are shown in Figure 5.1.

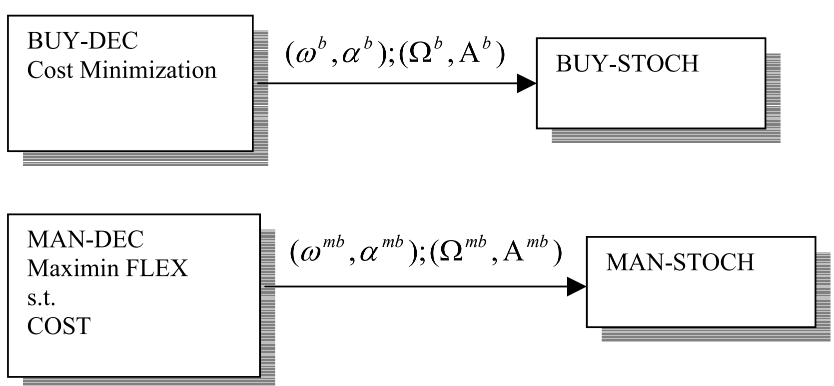

Figure 5.1 The Flexibility Parameters as Decision Variables and Parameters

The decision process of the flexibility parameters of the second buyer and the manufacturer, and the interaction between the two SC actors are presented in Figure 5.2.

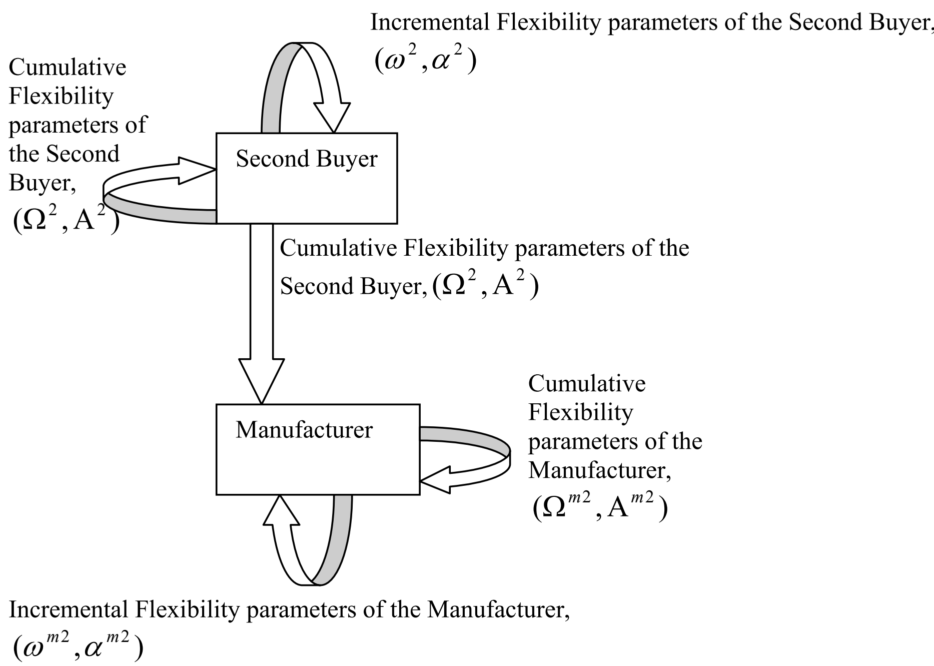

Figure 5.2 Decision Process of the Second Buyer and its Interactions

The second buyer decides both the incremental and cumulative flexibility parameters which are utilized for her medium and short term decisions. The downward arc represents the interaction between the second buyer and the manufacturer. That is, the values of the parameters determined provide the lower and upper bounds for the replenishment amounts to be requested from the manufacturer. The manufacturer's tight and loose flexibility parameters are settled on by multiplying the parameters of the second buyer with R_T and R_L, respectively. Since the tight flexibility of the first buyer is taken as a base, the R_L, i.e., the Loose Relative Flexibility, can be defined as follows;

$$R_L = \frac{Loose\ Flexibility\ of\ the\ Manufacturer\ for\ the\ First\ Buyer}{Tight\ Flexibility\ of\ the\ First\ Buyer} \quad (2)$$

The flexibility parameters of the second buyer at medium DEVAR level determined by solving a cost minimization model are as in Table 5.3.

Table 5.3 Flexibility Parameters of the Second Buyer at medium DEVAR level in the First Case

		FLEXIBILITY PARAMETERS [MEDIUM DEVAR]	
		ω^2	α^2
Period	1	0	1.131
	2	0	0
	3	0	0

, where $\omega^2 = [\omega^2_1, \omega^2_2, \omega^2_3]$, and $\alpha^2 = [\alpha^2_1, \alpha^2_2, \alpha^2_3]$.

The zero downward flexibility of all periods and zero upward flexibility of the second and third periods are typical values in fact implying a strict flexibility option. Especially, the values of the second period indicate that the estimated replenishment amount in the second period can not be modified as time passes, because both downward and upward flexibilities are zero. However, they are still optimal for her.

The tight and loose flexibilities of the manufacturer for both buyers at the medium level of DEVAR, given the second buyer sets her contract parameters, are presented in Table 5.4.

Table 5.4 Flexibility Parameters of the Manufacturer at medium DEVAR level and in different FLEX levels in the First Case

		FLEXIBILITY TIGHTNESS [MEDIUM DEVAR]							
		SECOND BUYER DETERMINES HER CONTRACT PARAMETERS							
		for FIRST BUYER				for SECOND BUYER			
		tight		loose		tight		loose	
		ω^{m1}	α^{m1}	ω^{m1}	α^{m1}	ω^{m2}	α^{m2}	ω^{m2}	α^{m2}
Period	1	0.1	0.1	0.2	0.2	0.05	1.23	0.16	1.44
	2	0.11	0.11	0.21	0.21	0.05	0.05	0.16	0.14
	3	0.12	0.11	0.22	0.22	0.05	0.05	0.16	0.14

, where $\omega^{m1} = [\omega^{m1}_1, \omega^{m1}_2, \omega^{m1}_3]$, and $\alpha^{m1} = [\alpha^{m1}_1, \alpha^{m1}_2, \alpha^{m1}_3]$; and $\omega^{m2} = [\omega^{m2}_1, \omega^{m2}_2, \omega^{m2}_3]$, and $\alpha^{m2} = [\alpha^{m2}_1, \alpha^{m2}_2, \alpha^{m2}_3]$.

The incremental flexibilities of the manufacturer for the second buyer are determined by multiplying the flexibility values determined by the second buyer with R_T and R_L for tight and loose levels, respectively. Therefore, in this case, first the second buyer determines her parameters, and then the manufacturer does.

The flexibility parameters of the second buyer at high DEVAR level are as in Table 5.5.

Table 5.5 Flexibility Parameters of the Second Buyer at high DEVAR level in the First Case

		FLEXIBILITY PARAMETERS [HIGH DEVAR]	
		ω^2	α^2
Period	1	0	1.24
	2	0	0
	3	0	0.044

, where $\omega^2 = [\omega^2_1, \omega^2_2, \omega^2_3]$, and $\alpha^2 = [\alpha^2_1, \alpha^2_2, \alpha^2_3]$.

In high DEVAR, it is observed that the second buyer tries to have higher flexibility values with respect to medium level. However, the zero value of the downward flexibilities of all periods does not change meaning that they are still optimal for her.

The tight and loose flexibility parameters of the manufacturer for the high level of the factor DEVAR, for the second buyer's offering her contract parameters, is presented in Table 5.6.

Table 5.6 Flexibility Parameters of the Manufacturer in high DEVAR level and in different FLEX levels in the First Case

		FLEXIBILITY TIGHTNESS [HIGH DEVAR]							
		SECOND BUYER DETERMINES HER CONTRACT PARAMETERS							
		for FIRST BUYER				for SECOND BUYER			
		tight		loose		tight		loose	
		ω^{m1}	α^{m1}	ω^{m1}	α^{m1}	ω^{m2}	α^{m2}	ω^{m2}	α^{m2}
Period	1	0.1	0.1	0.2	0.2	0.05	1.35	0.16	1.56
	2	0.11	0.11	0.21	0.21	0.05	0.05	0.16	0.14
	3	0.12	0.11	0.22	0.22	0.05	0.09	0.16	0.19

, where $\omega^{m1} = [\omega^{m1}_1, \omega^{m1}_2, \omega^{m1}_3]$, and $\alpha^{m1} = [\alpha^{m1}_1, \alpha^{m1}_2, \alpha^{m1}_3]$; and $\omega^{m2} = [\omega^{m2}_1, \omega^{m2}_2, \omega^{m2}_3]$, and $\alpha^{m2} = [\alpha^{m2}_1, \alpha^{m2}_2, \alpha^{m2}_3]$.

In the second case, the manufacturer determines first his own flexibility parameters, and then the parameters to be offered to the second buyer. The manufacturer first intends to offer such contract flexibility parameters that they will be appealing to the second buyer in order to involve her into the supply chain game. The second buyer's flexibility parameters are settled on by dividing the determined parameters of the manufacturer by the tight relative flexibility, R_T stated in the first case.

Since the cumulative flexibility parameters, Ω and A 's, are formed from the incremental flexibility parameters, ω and α 's, we compute only the incremental flexibility parameters in our analysis. We try to maximize the least incremental flexibility parameter to be offered to the second buyer. However, this is related to the cost which is comprised of the inventory carrying and subcontracting costs of the manufacturer.

We first find the minimum total cost in the Worst Case Problem, while not taking the choice of the flexibility parameters into account. This is achieved by solving the initial model where the largest replenishment amounts are included. Then, we include the optimal WCP cost as a total cost constraint to the other problem where the lowest incremental flexibility parameters are maximized.

We try to see the effect of the flexibility parameters offered to the second buyer on the manufacturer. Thus, instead of writing the maximum of the possible replenishment occurrences into the WCP, we include the largest amount possible that can be requested by the second buyer from the manufacturer given the opportunity of the QF contract. This critical amount is the upper bound formed by the estimated replenishment amount in the previous period times the cumulative flexibility, i.e., $(1 + A^2{}_j)$. The $A^2{}_j$'s are found by dividing the flexibility parameters of the manufacturer for the second buyer by the tight relative flexibility, R_T that is given to the first buyer.

We see that when the constraint setting an upper bound to the total cost of WCP is relaxed, the flexibility parameters increase. That is, there is a tradeoff between the total cost to the manufacturer and flexibility offered to the second buyer. We make some pilot runs to examine the effect of the total cost limitation on the flexibility.

Table 5.7 Total Cost versus Downward Incremental Flexibility

		Downward Incremental Flexibility		
		1st Period	2nd Period	3rd Period
Bound on Total Cost on the Manufacturer	2010	0.068	0.068	0.068
	2050	0.073	0.073	0.073
	2100	0.08	0.08	0.08
	2400	0.12	0.155	0.144
	2700	0.158	0.737	0.158

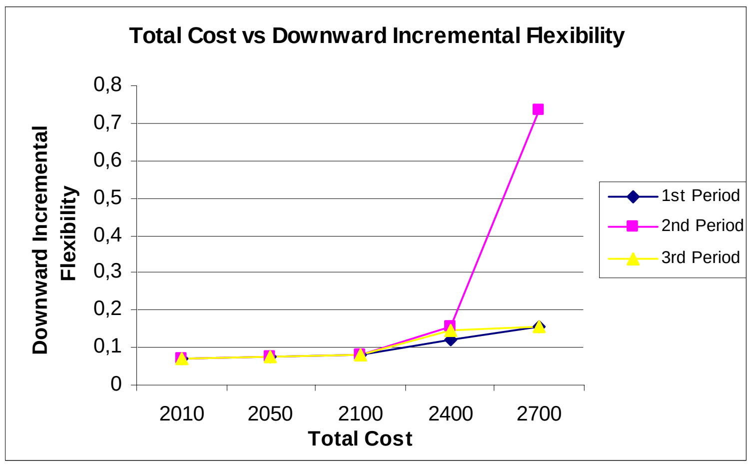

Figure 5.3 Total Cost versus Downward Incremental Flexibility Graph

Table 5.8 Total Cost versus Upward Incremental Flexibility

		Upward Incremental Flexibility		
		1st Period	2nd Period	3rd Period
Bound on Total Cost On the Manufacturer	2010	0.068	0.068	0.068
	2050	0.073	0.073	0.073
	2100	0.08	0.08	0.08
	2400	0.12	0.12	0.12
	2700	0.158	0.158	0.158

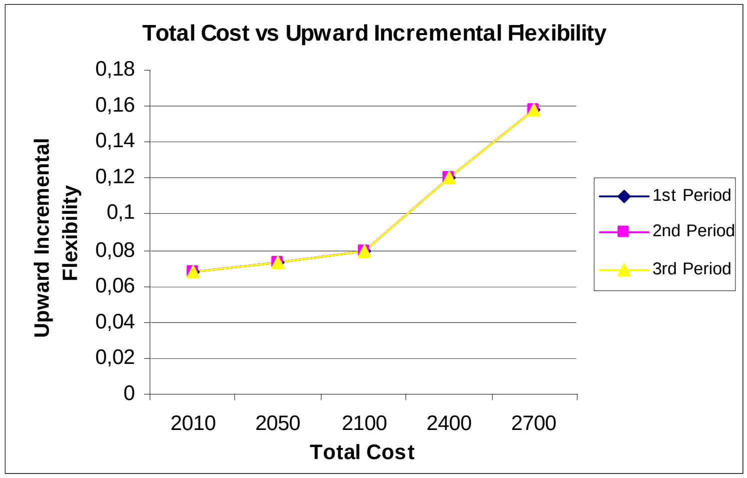

Figure 5.4 Total Cost versus Upward Incremental Flexibility Graph

The graphs in Figure 5.3 and 5.4 are obtained from the pilot runs applied for the medium DEVAR and tight FLEX in the first buyer's case. According to the graphs displayed above, we can easily see the tradeoff between the total cost, and downward and upward incremental flexibility parameters. This tradeoff implies that the flexibility offered to the second buyer by the manufacturer in fact implies a cost effect onto the manufacturer. This is due the characteristics of the QF contract. For instance, although the second buyer gives a low estimation for her replenishment amounts, she can request a larger amount from the manufacturer, if she is given a high flexibility option. Then in turn, the manufacturer who guarantees the replenishment amount is forced to do subcontracting. Or when the opposite occurs, that is, when the second buyer orders less than the estimated replenishment amount, the manufacturer is obliged to carry inventory more than he expected.

For the analysis of the three factors on the performance of the SC actors, the optimal total cost of WCP (OTC_{WCP}) is set as an upper limit into the model where the flexibility parameters are determined. The upper or lower cost values than OTC_{WCP}

are not included, since the optimal WCP cost is the critical cost level, where the largest replenishment amounts possible are included to the initial model.

The tight and loose flexibilities of the manufacturer for both buyers for DEVAR set at medium level can be seen in Table 5.9.

Table 5.9 Flexibility Parameters of the Manufacturer at medium DEVAR level and in different FLEX levels in the Second Case

		FLEXIBILITY TIGHTNESS [MEDIUM DEVAR]							
		MANUFACTURER DETERMINES THE CONTRACT PARAMETERS							
		for FIRST BUYER				for SECOND BUYER			
		tight		loose		tight		loose	
		ω^{m1}	α^{m1}	ω^{m1}	α^{m1}	ω^{m2}	α^{m2}	ω^{m2}	α^{m2}
Period	1	0.1	0.1	0.2	0.2	0.068	0.068	0.093	0.093
	2	0.11	0.11	0.21	0.21	0.068	0.068	0.093	0.093
	3	0.12	0.11	0.22	0.22	0.068	0.068	0.093	0.093

, where $\omega^{m1} = [\omega^{m1}_1, \omega^{m1}_2, \omega^{m1}_3]$, and $\alpha^{m1} = [\alpha^{m1}_1, \alpha^{m1}_2, \alpha^{m1}_3]$; and $\omega^{m2} = [\omega^{m2}_1, \omega^{m2}_2, \omega^{m2}_3]$, and $\alpha^{m2} = [\alpha^{m2}_1, \alpha^{m2}_2, \alpha^{m2}_3]$.

Then, the tight and loose flexibility parameters of the second buyer offered by the manufacturer, at medium DEVAR level, are as in Table5.10.

Table 5.10 Flexibility Parameters of the Second Buyer at medium DEVAR level in the Second Case

		FLEXIBILITY TIGHTNESS [MEDIUM DEVAR]			
		tight		loose	
		ω^2	α^2	ω^2	α^2
Period	1	0.016	0.019	0.043	0.043
	2	0.016	0.020	0.042	0.044
	3	0.015	0.020	0.041	0.044

, where $\omega^2 = [\omega^2_1, \omega^2_2, \omega^2_3]$, and $\alpha^2 = [\alpha^2_1, \alpha^2_2, \alpha^2_3]$.

Since the loose flexibility option is provided to the manufacturer by increasing the upper total cost limit, these incremental flexibility values are determined by dividing the flexibility parameters of the manufacturer for the second buyer by R_T.

The tight and loose flexibility parameters of the manufacturer for DEVAR factor at the high level are presented in Table 5.11.

Table 5.11 Flexibility Parameters of the Manufacturer at high DEVAR level and in different FLEX levels in the Second Case

		FLEXIBILITY TIGHTNESS [HIGH DEVAR]							
		MANUFACTURER DETERMINES THE CONTRACT PARAMETERS							
		for FIRST BUYER				for SECOND BUYER			
		tight		loose		tight		loose	
		ω^{m1}	α^{m1}	ω^{m1}	α^{m1}	ω^{m2}	α^{m2}	ω^{m2}	α^{m2}
Period	1	0.1	0.1	0.2	0.2	0.117	0.117	0.139	0.139
	2	0.11	0.11	0.21	0.21	0.117	0.117	0.14	0.139
	3	0.12	0.11	0.22	0.22	0.128	0.117	0.139	0.139

, where $\omega^{m1} = [\omega^{m1}_1, \omega^{m1}_2, \omega^{m1}_3]$, and $\alpha^{m1} = [\alpha^{m1}_1, \alpha^{m1}_2, \alpha^{m1}_3]$; and $\omega^{m2} = [\omega^{m2}_1, \omega^{m2}_2, \omega^{m2}_3]$, and $\alpha^{m2} = [\alpha^{m2}_1, \alpha^{m2}_2, \alpha^{m2}_3]$.

Then, the tight and loose flexibility parameters of the second buyer offered by the manufacturer at high DEVAR level are as in Table 5.12.

Table 5.12 Flexibility Parameters of the Second Buyer at high DEVAR level in the Second Case

		FLEXIBILITY TIGHTNESS [HIGH DEVAR]			
		tight		loose	
		ω^2	α^2	ω^2	α^2
Period	1	0.068	0.066	0.091	0.087
	2	0.067	0.067	0.092	0.088
	3	0.078	0.067	0.090	0.088

, where $\omega^2 = [\omega^2_1, \omega^2_2, \omega^2_3]$, and $\alpha^2 = [\alpha^2_1, \alpha^2_2, \alpha^2_3]$.

COST

For the final factor, cost, the levels are determined such that the cost burden on each party can be easily controlled. Since SC actors exist in the same environment; we assume they have the identical inventory carrying costs. As described in the previous section, the inventory costs of the buyers and the manufacturer are taken as the base, and all the other costs are determined accordingly. We also assume that cost values do not differ from period to period. The unit costs for the buyers and the manufacturer can be seen in Table 5.13.

Table 5.13 Unit Costs of the Supply Chain Actors

	COST ($)	
	Low	High
inventory holding cost	1	1
backordering cost	3	8
subcontracting cost	2	4
immediate subcontracting cost	4	8

According to the cost values presented in the table above, the tradeoff on the manufacturer's side arises in the backordering and subcontracting costs. The low cost values create no burden on any parties. However, by high backordering cost, the buyers are forced to carry more inventory in order not to experience shortage. However, this often results in requesting more from the manufacturer. Thus, the manufacturer who has a limited capacity is then forced to do more subcontracting, so has a high cost. Hence, the cost burden is given onto the buyer directly, and also onto the manufacturer indirectly. In the other case, in which the subcontracting cost is high, the manufacturer tries to do less subcontracting which is in relation with the replenishment amounts requested by the buyers, thus, by increasing the subcontracting cost, the burden is given onto the manufacturer. Lastly, when the costs of the SC parties are all high, the burden is given on all. That is, both buyers try to make less backordering and the manufacturer tries to do less subcontracting, hence the objectives are in severe conflict.

5.2.2 GENERATION OF DEMAND DATA

Since the market demand is stochastic, to introduce random market demand into the problem, a scenario based approach is utilized. The details of the scenario based approach are introduced in Chapter 3. For the scenario based approach, we generate discrete alternative values for each period except the current period at the beginning. The approach for data generation is based on the coefficient of variation (CV) of the data.

At the beginning of the planning horizon, it is assumed that the buyers have forecasts performed in the previous period. They are initially assumed given to the problem and they are taken as the mean of the demand of the related period. The market demand the buyers face over the horizon is not stationary. We assume they have some demand information about the market demands through all periods. They have an increasing coefficient of variation as going away from the current period, corresponding to an increasing forecast error. However, as time passes, the forecasts for the demand of the periods are modified by the buyers, forecast CV values gradually decrease. That is, getting closer to the current period, less uncertainty is encountered. Therefore, for consistency of treatment, the CV of the period (t+j) changes to the CV of period (t+j-1) after the calendar moves one period ahead.

According to the scenario tree introduced in chapter 3, the data for the first period, is a single value, since it is the realized market demand for the current period. The buyer has complete and accurate information for the current period alone. For the next, second and third periods, 4 possible demand occurrences are generated in each. Therefore, 4^3=64 scenarios are constructed. Each has its own chance to be realized.

For the generation of the data, the CV and the mean values are taken into account. The approach taken in the demand data generation is finding 4 discrete values that give the desired CV and mean, where the former represents the forecast error and the latter, the forecast of the SC actor for all periods except the current period.

An example of the scenario tree generated for the first buyer can be seen in Figure 5.5.

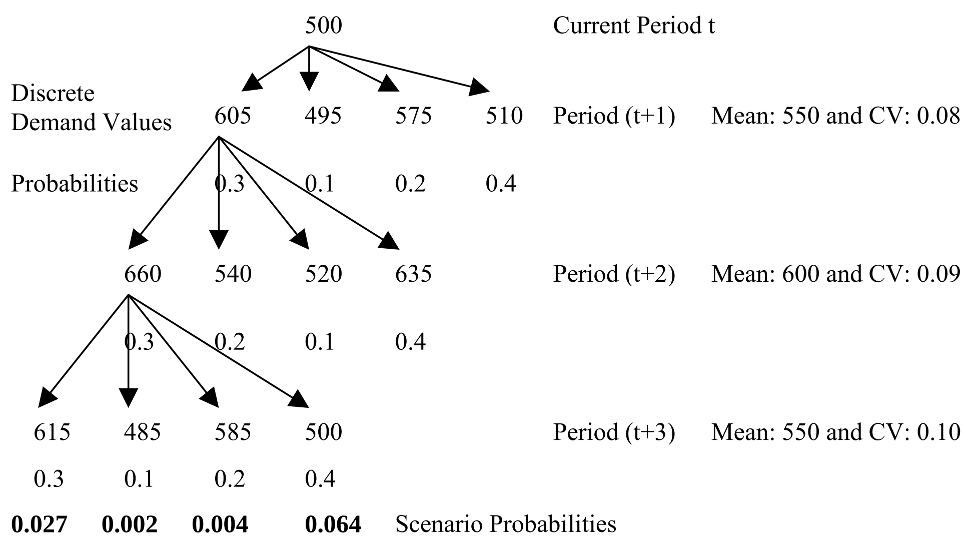

Figure 5.5 Scenario Tree generated for the First Buyer

On the first level of the scenario tree in the above figure, there is an exact value which is the realized market demand. At the second level, i.e., second period, and other levels as well, the mean represents the forecast of the buyer for that period. The discrete values are the random alternative demand occurrences along with their associated probabilities. The coefficient of variation at a level represents the variance of the discrete values at that level.

As one period passes, we go down on the scenario tree, another level is appended to the bottom, and the first level is omitted. This time the second period becomes the current period; the third period becomes the period just following the current period. The third and later periods now have different discrete values from the first scenario tree. They have different (lower) CV, since they become closer to the current period. However, they are assumed to have the same mean and the same probabilities. This is because probabilities refer to scenarios (i.e., $P(sc_i)=p_i$) and are independent of time. The demand data generated for the first and second buyers at particular demand variation levels are presented in Appendix A.

As in the buyer's case, it is also assumed that the forecasts made by the manufacturer in the previous period are supplied to the problem initially. The manufacturer forecasts the actual replenishments of the buyers with an increasing CV getting apart from the current period as well. To be consistent between the SC actors, the manufacturer and the buyers are assumed to have their initial forecasts identical to each other. Though the means of their forecasts are assumed to be the same for the periods, the discrete values, and the associated probabilities to these discrete values are different for the buyers and the manufacturer. Moreover, it is assumed that the manufacturer also modifies his forecasts about the actual replenishments of the buyers as time passes.

The manufacturer is subject to two independent scenario trees each related to a different buyer's replenishment amounts. On the first levels of the scenario trees, there are two exact values representing each buyer's realized actual replenishment amount. Since the manufacturer encounters two separate scenario trees for each buyer in the decisions of inventory carrying, production, capacity usage and subcontracting, he takes all combinations of the two 64 scenarios, thus he is subject to 64x64 cases in total. The demand data generated for the manufacturer at particular demand variation levels are presented in Appendix B.

We analyze the manufacturer's incentives in allocating his limited capacity and in his subcontracting decisions in a QF environment. The purpose is to examine at what amount the manufacturer uses his limited capacity, at what amount he gives orders to the subcontractor and in which situations he determines to subcontract. In order to determine the fixed capacity limit, we try to cover a large percentage of the total demands of the buyers. We select this percentage as 80%. The maximum of the sums of the demand estimations for each period made by each buyer is selected for calculation. According to the demand data generated for both buyers, the manufacturer's capacity is determined as 1000 units covering at least 80% of the maximum estimated total demand.

5.3 STATISTICAL ANALYSIS

In order to analyze the attitudes of the SC actors and their benefits gathered both in the individual and in the integrated supply chain environment, we conduct a statistical analysis on the performance measures determined. We try whether the performance measures obtained are significantly different for different levels of the three factors, DEVAR, FLEX, and COST.

We first determine the required sample size for the statistical analysis. For the first and second buyers, there are 64 scenarios having different probabilities of occurrence. In order to make our analysis on the performance measures determined for the SC actors, we determined the required sample size to construct a 90% confidence interval (CI) for the 64 scenarios. Since all periods in the planning horizon are independent from each other, we independently calculate the sample size for each period considering the mean and variation of that period's demand. According to the determined sample size for each period, the maximum sample size among all periods is obtained. Then, utilizing the Random Data Generation option of the statistical software MINITAB, we take a specified number of samples from 64 scenarios and make our analysis using these samples.

For the manufacturer, the randomness stem from the actual replenishment amounts of the two buyers. Therefore, in order to determine the required sample size, pilot runs are carried out. Same as the buyers' cases, the periods in the planning horizon are independent from each other. The required sample size is calculated for the first and the second buyer's replenishment amounts individually. The manufacturer is subject to the combination of both buyers' replenishment amounts, where they are also independent from each buyer's. Thus, the summation of the means and variations of first and second buyers for each period is also calculated to determine the sample size. The maximum among these three calculated sample sizes is taken to generate samples from the combination of 64 scenarios for each buyer, that is, from 64x64 scenarios. The samples generated for each SC actor is given in Appendix C.

The required sample size for the integrated supply chain is determined with the same approach utilized in the calculations of the manufacturer's required sample size.

5.4 GAMS MODEL

In order to solve the two-stage stochastic models constructed, the optimization software General Algebraic Modeling (GAMS) is run. This optimization software has many advantages that encourage us its use. It provides a high-level language for the compact representation of large and complex models, allows changes to be made in model specification simply and safely, permits model descriptions that are independent of solution algorithms, and finally solves more than one model in a single run.

Since our model gets larger as the number of scenarios gets larger, the GAMS/Cplex solver is selected. GAMS/Cplex allows for combining the high level modeling capabilities of GAMS with the power of Cplex optimizers. While numerous solving options are available, GAMS/Cplex automatically calculates and sets most options at the best values for specific problems.

Moreover, for the initial models in the case where the second buyer determines her flexibility parameters, and the case where the manufacturer determines the flexibility parameters to be offered to the second buyer, a non-linear programming model is solved. For the non-linear model, MINOS, which is a general purpose nonlinear programming solver is utilized. GAMS/MINOS is designed to find solutions that are locally optimal.

In the application of the Benders Decomposition Algorithm, there is a loop, where sub and master problems are iteratively solved. One single GAMS model is comprised of three models, which are the Worst Case Problem (WCP), the sub problem and the master problem. Initially, the WCP is solved. The solutions are introduced to the sub problem. By the LOOP option in GAMS, we construct a loop where the sub problem is solved first. The solutions of the sub problem at each iteration are saved in specified parameters, and are introduced to the master problem as numerical values. Thus, at each iteration one constraint is added to the master problem. Afterwards, the master problem is solved. Then the new master problem solutions are included into the sub problem as numerical values, and new sub problem is solved. When the terminating condition, which is written again at the beginning of the loop, is satisfied, the loop terminates. Thus, by the LOOP option, the two-stage stochastic programming models constructed are solved in a single run.

An example for the two-stage stochastic model of the first buyer applied in GAMS is presented in Appendix D.

CHAPTER VI

ANALYSIS

In this study, we analyze the attitudes of SC actors in a specified environment and their incentives in their medium and short term decisions. The environmental characteristics are comprised of who determines the contract flexibility parameters, how the values of the flexibility parameters are decided, the tightness of the flexibilities, the variability of the demand the SC actors face, and the costs associated with their medium and short term decisions.

Given the different factors levels explained in the previous chapter, and the decision making situations of the flexibility parameters for the second buyer, a full factorial experiment is performed. The objective of this experiment is to investigate the individual and system wide behaviors of the SC actors in different cases and under the effects of the environmental characteristics.

In this chapter, the effects of the factor levels on the average cost of each SC actor are analyzed statically utilizing the SAS (Statistical Analysis System) software. In $6.1, some initial observations related with the attitudes in the determination of the flexibility parameters and the character of typical sample runs, are presented. In $6.2, the approaches taken in modeling to compare different factors are stated. In $6.3, the outcomes of the full factorial experiment and the underlying reasoning behind these particular behaviors are proposed. Moreover, a statistical analysis to compare whether there is a significant difference between individual and coordinated activity is performed.

6.1 INITIAL OBSERVATIONS

Before analyzing the system in detail, we want to give some initial observations about the behavior of the SC actors in a given sample under specific factor levels.

In both cases, where the decision maker (DM) of the flexibility parameters to be applied to the second buyer differs, the DM's try to realize relatively higher flexibility parameter values as the DEVAR gets higher. This implies that as DEVAR gets higher, the willingness to use the flexibility options provided by the QF contracts and to pay the price for the option increases.

Although the constant capacity limit is set to cover at least 80% of the maximum total demand forecasts over the two buyers, the order amount given to the subcontractor is higher than 20%, which indicates that the manufacturer does not use his capacity in full. The reason for this is that the manufacturer opts to carry inventory into the future periods. Since he does not know the intended future replenishment amounts of the buyers by certainty, he makes his plans according to his forecasts. Thus, he tries to cover all possible forecasted replenishment values, and often gives larger than possibly needed orders to the subcontractor.

The manufacturer's average cost increases in the second case where he determines the flexibility parameters with respect to the one in the first case. This is due to the replenishment amounts requested by the second buyer. Since she determines the parameters herself in the first case, she makes contract obligations more efficient, that is, more effective bounds are constructed so that her estimates can fall within them. Thus, she can request less when a lower demand occurs, which in fact affects the cost of the manufacturer in a positive way.

We are also interested in the information sharing and control scheme of the SC actors, that is, their environments. The decisions of the buyers and the manufacturer in the individual and the integrated supply chain environments under identical realized demand quantities are presented below. The purpose is to display the change in the estimated replenishment amounts as time passes, and the changes in the decisions where all actors are involved in a single game. First, we present Table 6.1 and 6.2 for the SC actors to display their decisions through the passage of time for four periods.

Table 6.1 Notations of the First Buyer's Decisions on a Rolling Horizon

FIRST BUYER							
t=1	**$\mu_0 1(1)$**	**t=2**	**$\mu_0 1(2)$**	**t=3**	**$\mu_0 1(3)$**	**t=4**	**$\mu_0 1(4)$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
inv1(0) back1(0)	inv1(1) back1(1)	inv1(1) back1(1)	inv1(2) back1(2)	inv1(2) back1(2)	inv1(3) back1(3)	inv1(3) back1(3)	inv1(4) back1(4)
$f_1 1(0)$	**$f_0 1(1)$**						
$f_2 1(0)$	$f_1 1(1)$	$f_1 1(1)$	**$f_0 1(2)$**				
$f_3 1(0)$	$f_2 1(1)$	$f_2 1(1)$	$f_1 1(2)$	$f_1 1(2)$	**$f_0 1(3)$**		
	$f_3 1(1)$	$f_3 1(1)$	$f_2 1(2)$	$f_2 1(2)$	$f_1 1(3)$	$f_1 1(3)$	**$f_0 1(4)$**
	$f_0 1(2)$		$f_3 1(2)$	$f_3 1(2)$	$f_2 1(3)$	$f_2 1(3)$	$f_1 1(4)$
	$f_0 1(3)$		$f_0 1(3)$		$f_3 1(3)$	$f_3 1(3)$	$f_2 1(4)$
	$f_0 1(4)$		$f_0 1(4)$		$f_0 1(4)$		$f_3 1(4)$
			$f_0 1(5)$		$f_0 1(5)$		$f_0 1(5)$
					$f_0 1(6)$		$f_0 1(6)$
							$f_0 1(7)$

Every period is depicted in two columns, denoted by “before” and “after”. The former shows input data coming from the end of the previous period which is utilized in the current period. The latter shows the decisions of the current period and the input data to be exploited in the next period. The decisions of not only the estimated replenishments in period t, $f_j b(t)$'s, but also the inventory carrying or backordering as of end of period t, $invb(t)$ and $backb(t)$ are transferred to the next period (t+1) as input. The $f_j b(t)$'s are also conveyed to the manufacturer. The $f_0 b(t)$'s are the actual replenishment amounts decided according to the realized demand, $\mu_0 b(t)$'s. The $f_0 b(t+j)$'s are the intended future replenishment amounts, which are in fact the internal plans and which will be the actual replenishment amount as period (t+j) becomes the current period. As seen from the table above, there is a dynamics through all periods. For instance, the estimate for the third period made initially, $f_3 1(0)$ changes to the estimate made in the first period $f_2 1(1)$, then to the estimate made in the second period $f_1 1(2)$, and eventually the actual replenishment amount requested in the third period $f_0 1(3)$.

Table 6.2 Notations of the Manufacturer's Decisions on a Rolling Horizon

MANUFACTURER							
For First Buyer							
t=1	**$f_0 1(1)$**	**t=2**	**$f_0 1(2)$**	**t=3**	**$f_0 1(3)$**	**t=4**	**$f_0 1(4)$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
invmp1(0)	subexp1 invm1(1)	invmp1(1)	subexp1 invm1(2)	invmp1(2)	subexp1 invm1(3)	invmp1(3)	subexp1 invm1(4)
$r_1 1(0)$	**$r_0 1(1)$**						
$r_2 1(0)$	$r_1 1(1)$	$r_1 1(1)$	**$r_0 1(2)$**				
$r_3 1(0)$	$r_2 1(1)$	$r_2 1(1)$	$r_1 1(2)$	$r_1 1(2)$	**$r_0 1(3)$**		
	$r_3 1(1)$	$r_3 1(1)$	$r_2 1(2)$	$r_2 1(2)$	$r_1 1(3)$	$r_1 1(3)$	**$r_0 1(4)$**
	$r_0 1(2)$		$r_3 1(2)$	$r_3 1(2)$	$r_2 1(3)$	$r_2 1(3)$	$r_1 1(4)$
	$r_0 1(3)$		$r_0 1(3)$		$r_3 1(3)$	$r_3 1(3)$	$r_2 1(4)$
	$r_0 1(4)$		$r_0 1(4)$		$r_0 1(4)$		$r_3 1(4)$
			$r_0 1(5)$		$r_0 1(5)$		$r_0 1(5)$
					$r_0 1(6)$		$r_0 1(6)$
For Second Buyer							$r_0 1(7)$
t=1	**$f_0 2(1)$**	**t=2**	**$f_0 2(2)$**	**t=3**	**$f_0 2(3)$**	**t=4**	**$f_0 2(4)$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
invmp2(0)	subexp2 invm2(1)	invmp2(1)	subexp2 invm2(2)	invmp2(2)	subexp2 invm2(3)	invmp2(3)	subexp2 invm2(4)
$r_1 2(0)$	**$r_0 2(1)$**						
$r_2 2(0)$	$r_1 2(1)$	$r_1 2(1)$	**$r_0 2(2)$**				
$r_3 2(0)$	$r_2 2(1)$	$r_2 2(1)$	$r_1 2(2)$	$r_1 2(2)$	**$r_0 2(3)$**		
	$r_3 2(1)$	$r_3 2(1)$	$r_2 2(2)$	$r_2 2(2)$	$r_1 2(3)$	$r_1 2(3)$	**$r_0 2(4)$**
	$r_0 2(2)$		$r_3 2(2)$	$r_3 2(2)$	$r_2 2(3)$	$r_2 2(3)$	$r_1 2(4)$
	$r_0 2(3)$		$r_0 2(3)$		$r_3 2(3)$	$r_3 2(3)$	$r_2 2(4)$
	$r_0 2(4)$		$r_0 2(4)$		$r_0 2(4)$		$r_3 2(4)$
			$r_0 2(5)$		$r_0 2(5)$		$r_0 2(5)$
					$r_0 2(6)$		$r_0 2(6)$
							$r_0 2(7)$
	sub(2)		sub(3)		sub(4)		sub(5)

The table above is similar to the buyer's tables. It is composed of two separate tables one for the first and one for the second buyer. The $f_0 1(t)$, as can be followed in Table 6.1 and $f_0 2(t)$'s are the realized replenishment amounts of the first and second buyers in period t, respectively. The manufacturer has release schedules specific for each buyer. The decisions of not only the estimated releases in period t, $r_j b(t)$'s, but also the subcontracting, $sub(t+1)$'s, are conveyed to the next period (t+1) as in the buyers' cases. $sub\exp b(t)$'s are the immediate subcontracting decisions not transferred to the next period. $invmb(t)$'s are the resultant inventory in period t, and $invmpb(t)$'s are the inventory taken from the total pooled inventory in period t which will be used in period (t+1) (i.e., $invm1(t)$ and $invm2(t)$ can be realloacted). $r_0 b(t+j)$'s are the intended future release amounts that can be modified on a rolling horizon basis. $sub(t+1)$'s refer to the order given to the subcontractor in period t to be received in period (t+1).

The example is given for the case where the second buyer determines the flexibility parameters. The DEVAR level is high, and the FLEX level of both the first buyer and the manufacturer are tight. In the sample, the demand realizations for the first buyer are 500, 600, 720, and 440 units for the first, second, third, and fourth periods, respectively. The actual and estimated replenishment, inventory carrying and backordering decisions taken in the individual environment of the first buyer are presented in Table 6.3.

Table 6.3 Decisions of the First Buyer in her Individual (Decentralized) Environment

FIRST BUYER	**INDIVIDUAL ENVIRONMENT**						
t=1	**$\mu_0 1(1)=500$**	**t=2**	**$\mu_0 1(2)=600$**	**t=3**	**$\mu_0 1(3)=720$**	**t=4**	**$\mu_0 1(4)=440$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
inv1(0)=0	inv1(1)=0	inv1(1)=0	inv1(2)=0	inv1(2)=0	inv1(3)=0	inv1(3)=0	inv1(4)=151.7
back1(0)=0	back1(1)=0	back1(1)=0	back1(2)=0	back1(2)=0	back1(3)=5.5	back1(3)=5.5	back1(4)=0
500.0	**500**						
550.0	583.0	583.0	**600**				
660.0	642.0	642.0	680.5	680.5	**714.5**		
	577.9	577.9	593.0	593.0	628.6	628.6	**597.1**
			604.5	604.5	646.9	646.9	608.0
					554.2	554.2	579.7
							503.8

Since the estimated replenishment amount for the third period determined in the second period is low (680.5 relative to the realized demand 720), the first buyer unavoidably backorders some part of the third period's demand. However, due to the backordering, she determines the estimated replenishments to be utilized in the next period, with higher values. However, in the fourth period, she realizes a low demand again, and ends up with inventory. She, in turn, lowers her estimated replenishment amounts, as seen in the table above. For instance, the value of $f_3 1(2)$, i.e., 604.5 units, which refers to the fifth period's estimate in the second period happens to be enlarged to 646.9 units in third period, and in the fourth period, the estimate, $f_1 1(4)$ takes the lower value of 608 units. For the intended future replenishment amounts, no numerical values are included, since the internal plans are determined subject to each 64 scenario. This situation for the intended future replenishment and release amounts is also valid for the other SC actors.

The decisions of the second buyer in a sample are included in Table 6.4.

Table 6.4 Decisions of the Second Buyer in her Individual Environment

SECOND BUYER	**INDIVIDUAL ENVIRONMENT**						
t=1	**$\mu_0 2(1)=550$**	**t=2**	**$\mu_0 2(2)=650$**	**t=3**	**$\mu_0 2(3)=740$**	**t=4**	**$\mu_0 2(4)=720$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
inv2(0)=0 back2(0)=0	inv2(1)=0 back2(1)=0	inv2(1)=0 back2(1)=0	inv2(2)=0 back2(2)=0	inv2(1)=0 back2(1)=0	inv2(2)=0 back2(2)=0	inv2(1)=0 back2(1)=0	inv2(2)=0 back2(2)=0.1
550.0	**550**						
600.0	600.0	600.0	**650**				
650.0	650.0	650.0	650.0	650.0	**740**		
	307.8	307.8	321.4	321.4	321.4	321.4	**719.9**
			342.0	342.0	357.1	357.1	357.1
					307.8	307.8	321.4
							282.2

Since her downward incremental flexibilities, ω_j's, for all periods and the upward, α_j's for the second period are zero, the estimated replenishment amount of period (t+2) can not be modified as time passes. As seen from the table above, the value of $f_2 1(1)$, i.e., the estimate for the third period made in the first period, is 650 units, which does not change as time passes. The value of $f_1 1(2)$, i.e., the estimate in the second period, is again 650 units.

The replenishment amounts determined by the two buyers are requested from the manufacturer. The manufacturer being ordered the realized replenishment amounts makes the following set of decisions presented in Table 6.5.

Table 6.5 Decisions of the Manufacturer in his Individual Environment

MANUFACTURER		**INDIVIDUAL ENVIRONMENT**					
For First Buyer							
t=1	**$f_0 1(1)=500$**	**t=2**	**$f_0 1(2)=600$**	**t=3**	**$f_0 1(3)=714.5$**	**t=4**	**$f_0 1(4)=597.1$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
invmp1(0)=0	subexp1=22.5 invm1(1)=0	invmp1(1)=0	subexp1=0 invm1(2)=0	invmp1(2)=130	subexp1=0 invm1(3)=0	invmp1(3)=13	subexp1=0 invm1(4)=30.6
500.0	**477.5**						
550.0	600.0	600.0	**600.0**				
600.0	589.7	589.7	536.6	536.6	**584.5**		
	482.5	482.5	540.4	540.4	599.8	599.8	**614.7**
			526.3	526.3	589.5	589.5	654.3
					482.5	482.5	540.4
For Second Buyer							453.2
t=1	**$f_0 2(1)=550$**	**t=2**	**$f_0 2(2)=650$**	**t=3**	**$f_0 2(3)=740$**	**t=4**	**$f_0 2(4)=719.9$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
invmp2(0)=0	subexp2=27.5 invm2(1)=0	invmp2(1)=0	subexp2=0 invm2(2)=130	invmp2(2)=0	subexp2=0 invm2(3)=45.7	invmp2(3)=32.7	subexp2=0 invm2(4)=32.7
500.0	**522.5**						
550.0	570.0	570.0	**780.0**				
600.0	617.5	617.5	586.6	586.6	**785.7**		
	267.7	267.7	291.7	291.7	306.3	306.3	**719.9**
			290.0	290.0	316.0	316.0	331.8
					267.7	267.7	291.7
							245.4
	sub(2)=380		sub(3)=370.2		sub(4)=334.6		sub(5)=437

It is observed that all realized replenishment amounts are satisfied by that period's release amounts and by the subcontracting and the inventory carried from the previous period, except the first period. The manufacturer is forced to immediately subcontract 22.5 and 27.5 units for the first and second buyer, respectively in the first period due to the insufficient capacity. The large subcontracting amounts can be easily detected. These large amounts are not only due to the limited capacity of the manufacturer. They are also built up in trying to carry inventory for the future periods. Since he doesn't know the intended future replenishment amounts of the buyers, he makes his plans according to his own forecasts. For instance, in the first period, his forecasts for the first buyer are 660, 440, 480, and 595 units for the second period. However, the first buyer's intended future replenishment amounts determined in the first period are 612.5, 553.85, and 600 units over all scenarios. Due to the obligation to release the requested replenishment amounts to be requested later, he tries to make his subcontracting decision covering all possible forecasted replenishments which are often larger than the internal self plans of the buyers.

The three tables, (Table 6.3-5), above are defined by the three SC actors' acting individually. Now three tables for the SC actors will be presented when they play the same supply chain game in a coordinated manner, with demand realizations for the two buyers held identical. The intuition is that, in this specific environment, the decisions of the first buyer and the manufacturer differ when the medium and short term decisions of each SC actor are accurately informed to each other.

Table 6.6 Decisions of the First Buyer in the Integrated Supply Chain (Centralized) Environment

FIRST BUYER	**INTEGRATED SUPPLY CHAIN ENVIRONMENT**						
t=1	**$\mu_0$1(1)=500**	**t=2**	**$\mu_0$1(2)=600**	**t=3**	**$\mu_0$1(3)=720**	**t=4**	**$\mu_0$1(4)=440**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
inv1(0)=0 back1(0)=0	inv1(1)=0 back1(1)=0	inv1(1)=0 back1(1)=0	inv1(2)=0 back1(2)=0	inv1(2)=0 back1(2)=0	inv1(3)=0 back1(3)=70	inv1(3)=0 back1(3)=70	inv1(4)=87.1 back1(4)=0
500.0	**500**						
550.0	583.0	583.0	**600**				
660.0	642.0	642.0	619.0	619.0	**650**		
	577.9	577.9	593.0	593.0	628.6	628.6	**597.1**
			604.5	604.5	646.7	646.7	607.9
					581.8	581.8	593.0
							503.8

Table 6.7 Decisions of the Second Buyer in the Integrated Supply Chain Environment

SECOND BUYER	**INTEGRATED SUPPLY CHAIN ENVIRONMENT**						
t=1	**$\mu_0$2(1)=550**	**t=2**	**$\mu_0$2(2)=650**	**t=3**	**$\mu_0$2(3)=740**	**t=4**	**$\mu_0$2(4)=720**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
inv2(0)=0 back2(0)=0	inv2(1)=0 back2(1)=0	inv2(1)=0 back2(1)=0	inv2(2)=0 back2(2)=0	inv2(1)=0 back2(1)=0	inv2(2)=0 back2(2)=0	inv2(1)=0 back2(1)=0	inv2(2)=0 back2(2)=0.1
550.0	**550**						
600.0	600.0	600.0	**650**				
650.0	650.0	650.0	650.0	650.0	**740**		
	307.8	307.8	321.4	321.4	321.4	321.4	**719.9**
			342.0	342.0	357.1	357.1	357.1
					307.9	307.9	321.4
							282.2

Table 6.8 Decisions of the Manufacturer in the Integrated Supply Chain Environment

MANUFACTURER		**INTEGRATED SUPPLY CHAIN ENVIRONMENT**					
For First Buyer							
t=1	**$f_0 1(1)=500$**	**t=2**	**$f_0 1(2)=600$**	**t=3**	**$f_0 1(3)=650$**	**t=4**	**$f_0 1(4)=597.1$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
invmp1(0)=0	subexp1=22.5 invm1(1)=0	invmp1(1)=0	subexp1=0 invm1(2)=0	invmp1(2)=12.2	subexp1=0 invm1(3)=0	invmp1(3)=0	subexp1=0 invm1(4)=61.5
500.0	**477.5**						
550.0	610.5	610.5	**600.0**				
600.0	643.0	643.0	579.9	579.9	**637.8**		
	503.1	503.1	563.5	563.5	600.0	600.0	**658.6**
			526.3	526.3	589.5	589.5	524.6
					506.5	506.5	567.3
For Second Buyer							438.6
t=1	**$f_0 2(1)=550$**	**t=2**	**$f_0 2(2)=650$**	**t=3**	**$f_0 2(3)=740$**	**t=4**	**$f_0 2(4)=719.9$**
Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
invmp2(0)=0	subexp2=27.5 invm2(1)=0	invmp2(1)=0	subexp2=0 invm2(2)=12.2	invmp2(2)=0	subexp2=0 invm2(3)=0	invmp2(3)=0	subexp2=68.6 invm2(4)=0
500.0	**522.5**						
550.0	570.0	570.0	**662.2**				
600.0	617.5	617.5	586.6	586.6	**740.0**		
	267.7	267.7	291.7	291.7	277.2	277.2	**651.3**
			297.4	297.4	324.1	324.1	313.5
					267.7	267.7	291.7
							245.4
	sub(2)=262.2		sub(3)=377.8		sub(4)=309.9		sub(5)=256.1

The manufacturer now sees the intended future replenishment decisions. He determines the amount of inventory carried and order to be given to the subcontractor based on these intended future plans. It can easily be observed that the amount of inventory carried and order given to the subcontractor definitely decrease in the integrated supply chain, (i.e., in the centralized environment). For instance, the $sub(2)$, $sub(4)$ and $sub(5)$ values decrease from 380, 334.6, and 437 units to 262.2, 309.9, and 256.1 units, respectively. Also, the inventory of 130 units carried from the second period to the third period decreases to 12.2 units in the integrated supply chain solution. However, in the integrated SC, the manufacturer is forced to use the immediate subcontracting option in the fourth period, whereas he doesn't order to the subcontractor in his individual environment.

The first buyer in turn does not get into a better position when he is involved into the integrated supply chain. She only backorders 5.5 units in her individual environment, whereas in the integrated SC, she backorders 70 units, which indeed yields high cost for her. But, the inventory carried in the fourth period of the first buyer decreases from 151.7 to 87.1 units.

Finally, for this particular sample, only the manufacturer favors to be involved in the integrated supply chain. The first buyer is willing to behave individually, because in order to make the systemwide performance better, the cost burden due to the subcontracting is put onto her. As a result of the information shared, the estimated replenishment and release amounts also change to a certain extent. However, the second buyer's estimates and decisions of inventory carrying and backordering do not change, indicating that the cost substitution occurs between the first buyer and the manufacturer. Being the DM of her flexibility parameters, i.e., figuring some part of the environmental characteristics, she gets the advantage of the flexibility parameters in her offered QF contract.

6.2. STATISTICAL EXPERIMENTATION MODELS

In order to analyze the consequences of the factor levels on the accrued costs of the SC actors, we construct different statistical models. The difference is sought by constructing multi factor models and single factor models. Single factor models are, in fact, multiple factors artificially combined in that the level of a single factor correspond to each possible combination of all the factor levels.

At the beginning, the two cases where the second buyer's parameters are determined by (a) the second buyer herself and (b) by the manufacturer are considered. The models are constructed separately for the two cases over the individual and integrated SC environments.

The characteristics of the experiment performed can be seen in detail in the Figures 6.1-3.

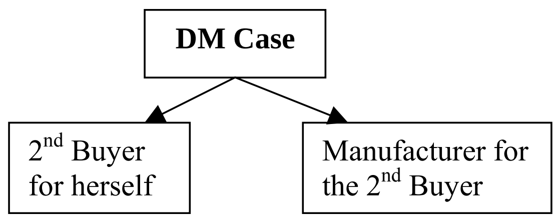

Figure 6.1 Different Cases for the Identity of the Decision Maker of the Second Buyer's Flexibility Parameters

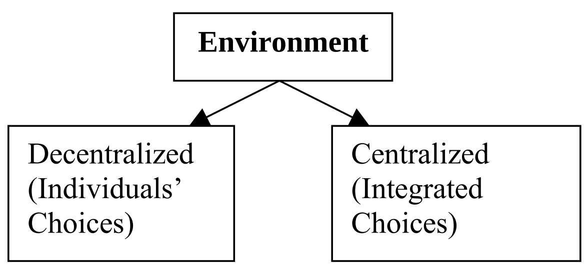

Figure 6.2 Different Environments in which the SC actors are involved

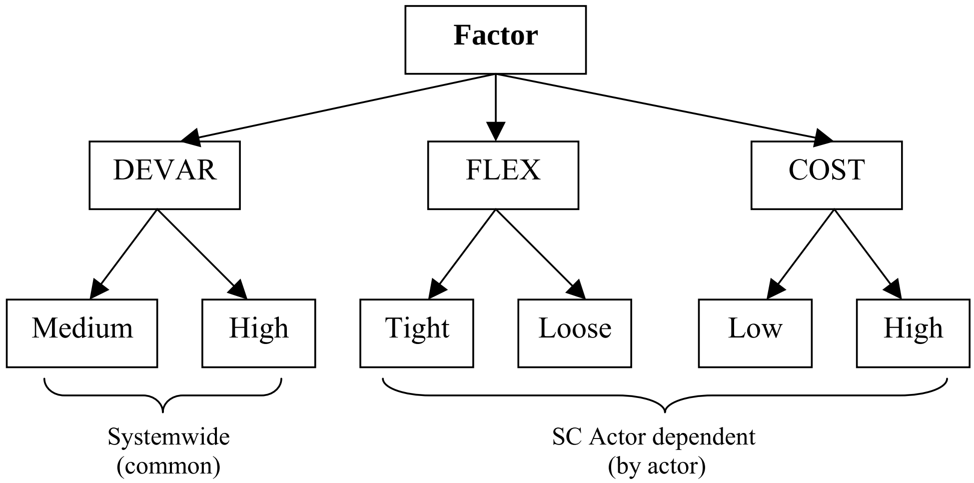

Figure 6.3 Different Levels of DEVAR, FLEX and COST Factors

As seen in Figure 6.3, the DEVAR factor is systemwide, whereas the FLEX and COST factors are dependent on the SC actors. In the first case, the tight and loose FLEX levels of the first buyer implies the incremental flexibility parameters that are utilized by her, and are in relation with the manufacturer with the cumulative flexibility parameters, which are in fact multiples of the incremental ones. The manufacturer in turn has tight and loose FLEX levels for each buyer, which are used for his own plans. In the second case, the tight and loose FLEX levels of the second buyer indicates the incremental flexibility parameters offered after the determination of the tight and loose incremental flexibility parameters of the manufacturer. The determination processes for both cases are explained in the previous chapter.

Different approaches in designing the models are taken into account. In the multi factor models, initially, the DEVAR factor is not involved, since it is a systemwide factor, whereas the others are SC actor dependent. The FLEX and COST factors are analyzed in different DEVAR levels to see the effects of the two factor levels in a particular environment. Then, to capture the effect of DEVAR where the other factors are assigned differently, models consisting of the three factor levels are constructed. Thirdly, all combinations of the FLEX and COST factor level are assigned as levels of a single factor. Finally, the DEVAR factor is also included, and every viable combination of levels for these three factors is treated as levels of a single factor. The aim in these last experiments is to see the effect of every combination of the factors within all possible combinations in the two different cases.

In the case, where the second buyer determines her own flexibility parameters, the factor levels to be analyzed differ for the SC actors both in the individual and in the integrated supply chain environments. Since the first buyer has loose and tight FLEX levels in her separate environment, a model having only two factors, FLEX and COST (with two levels for each factor) at different DEVAR levels is constructed. The model content is presented in Table 6.9.

Table 6.9 Statistical Model Content of the First Buyer in her Individual Environment

DEVAR level Medium (M) or High (H)		FLEXIBILITY TIGHTNESS(F_B,F_M)	
		tight (T,*)	loose (L,*)
COST(C_B,C_M)	low (L,*)		
	high (H,*)		

* represents all different levels of the manufacturer.

In Table 6.9, the notation (F_B,F_M) and (C_B,C_M) stands for the FLEX levels of the buyers and the manufacturer, and COST levels of the buyers and the manufacturer, respectively.

Since the second buyer determines her flexibility parameters, there are no loose or tight levels of her FLEX parameter. Hence, a model consisting of only one factor, COST with two levels, low and high is constructed at particular DEVAR levels for the second buyer.

As for the manufacturer, at a specific DEVAR level, the model has two factors, FLEX and COST, with four settings each. The four settings of each FLEX and COST factors are comprised of the combination of the buyers' and the manufacturer's FLEX levels and combination of two parties' COST levels, respectively. This is due to the fact that the loose or tight FLEX and low or high COST levels of the buyers in fact affect the actual replenishment amounts to be requested from the manufacturer. Since the decisions of inventory carrying, subcontracting and immediate subcontracting are related to the exact replenishment amounts, the manufacturer also faces effects of the FLEX and COST levels of the buyers. Hence, the manufacturer's model content can be presented in Table 6.10.

Table 6.10 Statistical Model Content of the Manufacturer in his Individual Environment

DEVAR Level		FLEXIBILITY TIGHTNESS(F_B,F_M)			
Medium (M) or High (H)		(T,T)	(T,L)	(L,T)	(L,L)
COST(C_B,C_M)	(L,L)				
	(L,H)				
	(H,L)				
	(H,H)				

For the integrated supply chain, all FLEX and COST levels affect individual costs of the SC actors. This is true as they act in a coherent system, where all information about the medium and short term decisions are perfectly shared. For instance, although the second buyer has no distinction as to loose or tight level of FLEX, the tight or loose FLEX levels of the first buyer and the manufacturer can influence the second buyer's costs through the interaction allowed over the coordinated environment.

In the case, where the manufacturer determines the flexibility parameter to be offered to the second buyer, the first buyer is allowed only the loose FLEX level. Therefore, the model for her is constructed with only one factor, COST with two levels, low and high. This is done not to have too many factor level interactions because this time, the second buyer is allowed to practice loose and tight FLEX levels. Thus, she has the same model type of the previous case with the first buyer. The model constructed for the second buyer has two factors, FLEX and COST with two levels each, which is presented in Table 6.11.

Table 6.11 Statistical Model Content of the Second Buyer in her Individual Environment

DEVAR level Medium (M) or High (H)		FLEXIBILITY TIGHTNESS(F_B,F_M)	
		tight (T,*)	loose (L,*)
COST(C_B,C_M)	low (L,*)		
	high (H,*)		

* represents all different levels of the manufacturer.

The models designed for the manufacturer and the SC actors in the integrated supply chain are the same as the models in the first case.

Apart from the analysis of the factor effects on the average costs of the SC actors separately, the average total system costs according to the individual versus the integrated supply chain environments are also investigated. This analysis is again based on all different levels of FLEX and COST factors at a given DEVAR level for both situations where the flexibility parameters of the second buyer are determined by her and by the manufacturer.

The average costs of the SC actors and the overall system in the decentralized and centralized environments with respect to different factor levels in the first DM case are presented in Table 6.12 and Table 6.13 below. The average cost table in both environments, in the second case can be seen in Appendix E and Appendix F.

Table 6.12 Average Costs of the SC Actors in the Decentralized Environment

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

		DECENTRALIZED ENVIRONMENT			
DEVAR	**(F_{B1}, F_M) / (C_B, C_M)**	1st Buyer	2nd Buyer	Manufacturer	Total
MEDIUM DEVAR	(T,T) / (L,L)	85.9	63.3	2360.0	2509.2
	(T,T) / (L,H)	85.9	63.3	4318.7	4467.9
	(T,T) / (H,L)	85.9	63.3	2360.1	2509.3
	(T,T) / (H,H)	85.9	63.3	4318.9	4468.1
	(T,L) / (L,L)	85.9	63.3	2359.2	2508.3
	(T,L) / (L,H)	85.9	63.3	4317.4	4466.6
	(T,L) / (H,L)	85.9	63.3	2359.2	2508.4
	(T,L) / (H,H)	85.9	63.3	4317.6	4466.8
	(L,T) / (L,L)	0.0	63.3	2313.4	2376.7
	(L,T) / (L,H)	0.0	63.3	4178.8	4242.1
	(L,T) / (H,L)	0.2	63.3	2313.6	2377.2
	(L,T) / (H,H)	0.2	63.3	4179.5	4243.1
	(L,L) / (L,L)	0.0	63.3	2312.5	2375.8
	(L,L) / (L,H)	0.0	63.3	4177.5	4240.8
	(L,L) / (H,L)	0.2	63.3	2312.7	2376.3
	(L,L) / (H,H)	0.2	63.3	4178.2	4241.8
HIGH DEVAR	(T,T) / (L,L)	290.1	86.8	3211.6	3588.5
	(T,T) / (L,H)	290.1	86.8	5913.4	6290.2
	(T,T) / (H,L)	370.7	86.8	3302.5	3760.0
	(T,T) / (H,H)	370.7	86.8	6095.4	6552.9
	(T,L) / (L,L)	290.1	86.8	3210.8	3587.6
	(T,L) / (L,H)	290.1	86.8	5912.7	6289.6
	(T,L) / (H,L)	370.7	86.8	3306.7	3764.2
	(T,L) / (H,H)	370.7	86.8	6084.2	6541.7
	(L,T) / (L,L)	130.6	86.8	3144.5	3361.8
	(L,T) / (L,H)	130.6	86.8	5711.8	5929.1
	(L,T) / (H,L)	130.9	86.8	3144.8	3362.5
	(L,T) / (H,H)	130.9	86.8	5712.5	5930.2
	(L,L) / (L,L)	130.6	86.8	3143.9	3361.2
	(L,L) / (L,H)	130.6	86.8	5710.9	5928.2
	(L,L) / (H,L)	130.9	86.8	3144.1	3361.8
	(L,L) / (H,H)	130.9	86.8	5711.5	5929.2

Table 6.13 Average Costs of the SC Actors in the Centralized Environment

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

		CENTRALIZED ENVIRONMENT			
DEVAR	**(F_{B1}, F_M) / (C_B, C_M)**	1st Buyer	2nd Buyer	Manufacturer	Total
MEDIUM DEVAR	(T,T) / (L,L)	129.1	75.0	1958.0	2162.2
	(T,T) / (L,H)	294.7	335.0	2363.0	2992.7
	(T,T) / (H,L)	166.1	83.1	2094.2	2343.3
	(T,T) / (H,H)	137.5	116.3	3986.3	4240.1
	(T,L) / (L,L)	118.3	103.3	1974.1	2195.7
	(T,L) / (L,H)	263.5	350.3	2373.6	2987.4
	(T,L) / (H,L)	140.1	73.3	2136.6	2350.0
	(T,L) / (H,H)	166.0	106.6	3970.7	4243.3
	(L,T) / (L,L)	174.7	80.1	1908.4	2163.3
	(L,T) / (L,H)	389.9	358.0	2257.8	3005.7
	(L,T) / (H,L)	186.1	80.7	2083.2	2350.0
	(L,T) / (H,H)	180.7	99.8	3969.5	4250.0
	(L,L) / (L,L)	146.7	89.9	1961.7	2198.3
	(L,L) / (L,H)	455.5	368.4	2305.6	3129.5
	(L,L) / (H,L)	145.1	80.0	2124.9	2350.0
	(L,L) / (H,H)	168.3	113.4	3968.3	4250.0
HIGH DEVAR	(T,T) / (L,L)	316.5	111.5	2523.2	2951.1
	(T,T) / (L,H)	696.1	980.3	2548.8	4225.2
	(T,T) / (H,L)	411.9	153.1	2680.8	3245.8
	(T,T) / (H,H)	472.3	159.3	5051.8	5683.4
	(T,L) / (L,L)	316.2	95.8	2539.1	2951.1
	(T,L) / (L,H)	689.8	969.2	2559.9	4218.9
	(T,L) / (H,L)	410.8	148.4	2684.9	3244.1
	(T,L) / (H,H)	474.6	150.4	5055.2	5680.2
	(L,T) / (L,L)	241.1	129.2	2477.2	2847.5
	(L,T) / (L,H)	714.0	785.0	2478.7	3977.7
	(L,T) / (H,L)	274.0	222.4	2613.5	3109.9
	(L,T) / (H,H)	289.2	205.2	4900.8	5395.3
	(L,L) / (L,L)	219.0	96.6	2536.8	2852.4
	(L,L) / (L,H)	654.1	764.8	2490.4	3909.3
	(L,L) / (H,L)	245.9	152.0	2705.2	3103.1
	(L,L) / (H,H)	288.1	161.1	4965.6	5414.7

MULTIPLE COMPARISON TESTS

In order to analyze the factor effects on accrued costs of the SC actors, multiple sample tests are applied. The SAS procedure PROC GLM (General Linear

Model) offers an option-rich procedure that performs many tests including ANOVA, and multiple sample tests such as Tukey's and Duncan's test.

ANOVA and a non-parametric test Kruskal-Wallis can only detect whether means vary among samples, but neither can tell which samples specifically differ or how they differ from one another. The multiple sample tests aim at simultaneous multiple pairwise comparison of many pairs of samples.

If we test all possible pairs of means using t-tests, the probability of type I error for the entire set of comparisons can increase dramatically. There are several procedures available to avoid this problem. Among the more popular of these procedures are the Newman-Keusl test, Tukey's test, and Duncan's multiple range tests. The most commonly used Tukey's test evaluates Type I experiment wise error rates (rather than comparison error rate obtained for individual tests) for multiple pairwise comparisons of means of all involved samples. There is also Duncan's test which tells whether a given mean differs from a given number of adjacent means. It is a result-guided test that compares the treatment means while controlling the comparison wise error rate and uses a least significance range value for sets of adjacent means.

Tukey's and Duncan's tests are selected for the comparison of the means at different factor levels. Not at all time, but in some cases, these two tests raise conflicts in their comparison results. According to the results of the two tests, the reasoning behind the consequences are tried to be explained.

6.3 ANALYSIS OF THE TEST RESULTS

In the statistical analysis, the main differences of the means of various factor levels for the SC actors are investigated first in individual and then in the integrated supply chain environments. The effects of the different levels of the factors on the behavior of the SC actors, their medium and short term decisions, and whether they benefit from knowing the others' decisions are all analyzed.

6.3.1 FIRST CASE: 2ND BUYER DETERMINES HER OWN FLEXIBILITY PARAMETERS

According to different DEVAR levels, in the first case, where the second buyer determines her flexibility parameters, the results of Tukey's and Duncan's tests in multi factor models for all SC actors in their decentralized environments, are summarized from the highest to lowest cost in Table 6.14 below.

Table 6.14 Cost Rankings and Comparison of Differences for SC Actors in the Decentralized Environment [First Case]

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
			FLEX (F_{B1},F_M)	COST (C_B,C_M)	FLEX (F_{B1},F_M)	COST (C_B,C_M)
2ND BUYER FOR HERSELF	DECENTRALIZED	FIRST BUYER	(T,*) (L,*)	(H,*) (L,*)	(T,*) (L,*)	(H,*) (L,*)
		SECOND BUYER		(H,*) (L,*)		(H,*) (L,*)
		MANUFACTURER	(T,T) (T,L) (L,T) (L,L)	(H,H) (L,H) (H,L) (L,L)	(T,T) (T,L) (L,T) (L,L)	(H,H) (L,H) (H,L) (L,L)

* represents all different levels of the manufacturer

In the first case, the first buyer is tested with tight and loose flexibility options. At both DEVAR levels, the average cost of the first buyer decreases as her flexibility parameters get looser. When a high or low demand is realized at the current period, her estimates comfortably fall within the bounds constructed by the flexibility constraints at the loose FLEX level. Due to the characteristics of the QF contract; the first buyer gets the benefit of flexibility option provided and either carries less inventory or backorders fewer units. However, when the COST factor level changes from low to high levels, the average costs do not differ significantly.

That is, the buyer gets very limited benefit with the low level of COST. According to the model constructed with the merged single factor where the level corresponds to each combinations of the FLEX and COST levels, the loose-low [(L,*)/(L,*)] combination favors all, but it is not found different from the loose-high [(L,*)/(H,*)] combination, whereas the tight-low [(T,*)/(L,*)] combination is put in a different group by both Tukey's and Duncan's tests. This result again supports the fact that the benefit obtained from the loose level of FLEX outweighs the benefit obtained from the low level of COST whether the level of DEVAR is medium or high. This is due to the fact that the replenishment amounts are decided more effectively by the option provided by the loose level of FLEX. All test results of the first case in single factor models are presented in Appendix G.

The second buyer has no loose or tight levels of FLEX, since she determines the flexibility parameters upon minimizing her inventory carrying and backordering costs. Being the decision maker (DM) also results in being indifferent to all DEVAR and COST levels. She also doesn't get into a better position as her unit costs decrease because she is given the option of deciding her flexibility parameters in all combinations of DEVAR and COST. For instance, at a particular DEVAR level, although she has high unit cost of inventory carrying and backordering, the decision of flexibility parameters do not differ from the low COST level. This due to the fixed (i.e., held constant across treatments) realized demand amount, and fixed demand estimations involved in her replenishment plans given the DEVAR level. According to the tests, she gets no advantage from the low level of COST. That is, being the DM of her own flexibility parameters outweighs the effects of the other factors.

The manufacturer on the other hand, does not get any benefit from the loose levels of FLEX for the first buyer and for himself at high DEVAR level. The manufacturer tries to carry inventory for the future periods, instead of using the flexibility option in certain cases though the realized replenishment amounts turn out to be less. Also, the subcontracting amounts decided according to forecasts of the replenishment amounts, are large most of the time. Those are due to trying to cover all possible replenishment forecasts since he doesn't know the exact intended future replenishment amounts of the buyers, nor is he accurately informed of the forecast distributions. Therefore, in some cases, when a relatively less amount of replenishment is realized, the excess subcontracting amount causes the manufacturer use his limited capacity not in full. Although he tries to compensate his excessive amount by low production later, he sometimes carries inventory since his estimated release amounts are already assigned to high values.

However, when the DEVAR level is medium, the FLEX level effects change. The combination of the loose level of the first buyer and the loose level of the manufacturer, i.e., (F_B,F_M)=(L,L), and (L,T) results in less cost onto the manufacturer than (T,L) and (T,T) combinations. That is, the benefit obtained by the loose FLEX level of the first buyer has a positive effect on the manufacturer due to the restricted replenishment amount requested. Also, loose FLEX of the first buyer outweighs the loose or tight FLEX level of the manufacturer. Although at both DEVAR levels, the first buyer gets the benefit of her flexibility option, the effect on the manufacturer is realized only in the medium DEVAR due to the uncertainty getting lower. Less variation in the replenishment forecasts leads to less subcontracting, less inventory carried for the future periods, and high capacity utilization, which is a good indication of the critical role played by more accurate information.

Also, at both DEVAR levels, the average costs of the manufacturer definitely increases when the COST level is high. This is due to the information asymmetry. Whether the inventory carrying and subcontracting costs increase or not, the replenishment amounts requested from the manufacturer do not change. Thus, the manufacturer who guarantees to release the realized replenishment amounts with his limited capacity gives the similar set of decisions, but at a higher cost for the high COST level.

The results of Tukey's and Duncan's tests for all SC actors for the centralized environment at different DEVAR levels, in the first case, are summarized from the highest to lowest cost in Table 6.15 below.

Table 6.15 Cost Rankings and Comparison of Differences for SC Actors in the Centralized Environment [First Case]

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
			FLEX (F_{B1},F_M)	COST (C_B,C_M)	FLEX (F_{B1},F_M)	COST (C_{B1},C_M)
2ND BUYER DETERMINES FOR HERSELF	CENTRALIZED	FIRST BUYER	(L,T) (L,L) (T,T) (T,L)	(L,H) (H,H) (H,L) (L,L)	(T,T) (T,L) (L,T) (L,T) (L,L)	(L,H) (H,H) (H,L) (H,L) (L,L)
		SECOND BUYER	(L,L) (T,L) (L,T) (T,T)	(L,H) (H,H) (L,L) (H,L)	(T,T) (T,L) (L,T) (L,L)	(L,H) (H,H) (H,L) (L,L)
		MANUFACTURER	(T,L) (T,T) (L,L) (L,T)	(H,H) (L,H) (H,L) (L,L)	(T,L) (T,T) (L,L) (L,T)	(H,H) (H,L) (L,H) (L,L)

Table 6.16 stands for the conflicting results of the Tukey's and Duncan's tests in the centralized environment for the first buyer and the manufacturer. Only, the results of the Duncan's test which are different from the Tukey's test are presented.

Table 6.16 Different Results of Duncan's Tests for the First Buyer and the Manufacturer in the Centralized Environment

DM Case	Environment	SC Actor	Medium DEVAR	
			FLEX (F_{B1},F_M)	COST (C_B,C_M)
2ND BUYER DETERMINES FOR HERSELF	CENTRALIZED	FIRST BUYER	(L,T) (L,L) (L,L) (T,T) (T,T) (T,L)	
		MANUFACTURER		(H,H) (L,H) (H,L) (L,L)

In the second buyer making decisions case, the attitudes of the SC actors at different levels of the factors change in the integrated supply chain over the decentralized (i.e., individuals') environment due to information sharing and being oriented systemwise. This time, the manufacturer's factor levels also affect the first buyer's decisions. The levels of FLEX raise differences for the first buyer in high DEVAR setting. The loose FLEX level again does good to the first buyer whether the manufacturer has tight or loose FLEX. Although the cost does not differ to her in the decentralized environment, the cost levels which are in fact effectual on the manufacturer's decision, have their impacts on the first buyer. For instance, the low COST levels of the buyers and the high levels for the manufacturer results in the highest average cost to her, since the system wide performance is taken into account.

To improve the system wide performance, some part of the cost burden arising from the high COST level of the manufacturer is directed to the first buyer. This means that when information is shared, instead of subcontracting, the first buyer is forced to backorder and requests less amount of replenishment from the manufacturer. However, when her unit inventory carrying and backordering costs are also high, the effects of the levels of the manufacturer's cost do not differ. That is, he gets into the best condition in the centralized environment only when the costs of the buyer and the manufacturer are at their low level. Hence, when the buyer has loose FLEX at the high COST level on parties, she does not favor information sharing from her point of view.

However, in medium DEVAR, the opportunities provided by loose FLEX level are lost. According to Tukey's test, the levels are indifferent, whereas according to Duncan's test, the FLEX combination set, (F_B,F_M)={(L,T), (L,L)} have higher costs than the set, {(T,T), (T,L)}. When the system wide performance is taken into consideration, the benefit arising from the manufacturer's loose flexibility has positive effect on the first buyer. That is, in medium DEVAR, the loose FLEX level of the manufacturer gives benefit not only to the manufacturer but also to the first buyer, while outweighing the benefit provided by the loose FLEX level of the first buyer. Again in medium DEVAR, the high COST level of the manufacturer results in the highest cost to the first buyer. However, according to Duncan's test in single factor model, when her cost is high, whether the cost of the manufacturer is high or not, she pays a higher cost with respect to the low COST levels of both actors. All these results in medium DEVAR are that the first buyer gets into a worse situation when the manufacturer is involved into the supply chain. That is, she can not utilize the flexibility option provided to her to fully reduce her costs, and the burden of the manufacturer's cost is partly transferred onto her. The reason of this situation at medium DEVAR level is indeed the lower uncertainty. When there is less variation, the first buyer favors behaving individually, whereas in high DEVAR, due to the increasing uncertainty, from the tight FLEX level point of view, she gets into a better or at least not worse position when the manufacturer is involved in the coordination.

For the second buyer acting in the integrated supply chain, according to the multi factor models, the FLEX levels of other parties cause indifferent average costs in high DEVAR, since she freely determines her optimal flexibility parameters. However, in the single factor model, only at the cost combination, $(C_B,C_M)=(L,H)$, the loose FLEX level of the manufacturer gives little benefit to her. When the FLEX level is set at a particular level, the low COST of her and the high of the manufacturer result in the highest average cost to her at both DEVAR levels. Although she has the low COST, the burden of the high COST of the manufacturer is directed to her. This means that instead of subcontracting which is definitely required due to the limited capacity of the manufacturer, the second buyer is forced not to meet some part of the realized demand on time for the entire chain's sake. She consequently requests less than immediately needed replenishment from the manufacturer.

However, the results of the usage of the flexibility options are different in the medium DEVAR. In multi-factor models, the loose levels of FLEX do not yield differences in her costs, since she determines her optimal flexibility parameters. However, in the model where all FLEX and COST combinations are assigned to a composite single factor, it is observed that at the cost combination $(C_B,C_M)=(L,H)$, loose level of the manufacturer negatively affects the second buyer, meaning that the cost of the flexibility option used by the manufacturer is billed to her. That is, when acting in an overall system dependent on the other actors, the second buyer is willing to have the manufacturer be tight in his medium and short term decisions, to be able to get the benefit from him. This way, the manufacturer is forced to accept the larger portion of the systemwide costs.

The manufacturer involved in the integrated supply chain gets no advantage from the loose FLEX level, in both medium and high DEVAR levels. When the single factor model for the manufacturer is analyzed at high DEVAR level, it is observed that when the manufacturer's flexibility parameters get looser, his costs increase when $(C_B,C_M)=\{(H,H), (H,L)\}$. Although the loose FLEX level of the manufacturer is expected to give benefit to the manufacturer, he gets into a worse situation. When the cost of both parties are high, i.e., cost burden is given on both parties, there is no way to decrease his costs. Thus, in order to make the system wide performance better, the benefit of the manufacturer due to the loose FLEX level is directed to the buyers. That is, the buyers try to make him be loose in his plans, and make not only themselves but also the overall system be in a better condition. Since the manufacturer has a limited capacity, i.e., has an inflexible environment, the cost of uncertainty is paid by him. That is, he is forced to carry larger inventory instead of using loose FLEX option in order not to use the expensive immediate subcontracting option in the future periods. However, when the level of DEVAR is medium, the manufacturer gets the benefit of loose FLEX level, in $(C_B,C_M)=(H,H)$ combination.

In high DEVAR, the manufacturer has the highest average cost at the cost combination $(C_B,C_M)=(H,H)$, since there is no way for him to be in a better condition. In medium DEVAR, all (C_B,C_M) levels result in different average costs for the manufacturer according to Duncan's test, meaning that all cost levels of the buyers and the manufacturer in fact affect the system wide performance. When the levels of COST are sorted in descending order of average cost, the sequence, (H,H), (L,H), (H,L) and (L,L) is obtained. The order implies that, the high cost of the manufacturer always results in high average costs for him and the integrated SC. The different resulting average costs among all COST levels exist in medium DEVAR due to the less uncertainty. That is, the significant effects of the cost are more deeply observed in medium DEVAR, meaning that less variation results in higher marginal differences for the manufacturer.

When all results of the tests with respect to decentralized and centralized environments are taken into consideration, it is observed that the manufacturer always favors to be involved in the coordinated environment. Due to his limited capacity, and due to trying to cover all replenishment forecasts, he often orders larger amounts to the subcontractor, which in fact results in not utilizing his established capacity in full. The stated case can be captured from an example given in Appendix H. For the example presented, the DEVAR level is high, and the FLEX and COST combinations are (F_B,F_M)=(T,T), (C_B,C_M)=(L,L), respectively. From the example constructed for both decentralized and centralized environments, it can easily be detected that, the subcontracting amounts decreases considerably, and capacity utilization increases, from 0.94% to 0.99%, which in fact yields lower costs to the manufacturer. On the other hand, especially the first buyer often favors not to be in the integrated supply chain, due to the cost burden of the manufacturer directed to her. Despite the negative consequences of the decentralized environment onto the overall system benefit, one actor is reluctant to play the coordinated game.

6.3.2 SECOND CASE: MANUFACTURER DETERMINES THE 2ND BUYER'S FLEXIBILITY PARAMETERS

In the second case, where the manufacturer determines the flexibility parameters to be offered to the second buyer, the analysis differs from the first case in some aspects. For instance, the first buyer is provided only loose FLEX level. And, this time, the second buyer is allowed to practice tight and loose FLEX levels in her incremental flexibility.

Table 6.17 summarizes the tests of the multi factor model results for all SC actors in their decentralized environments, with respect to different DEVAR levels.

Table 6.17 Cost Rankings and Comparison of Differences for SC Actors in the Decentralized Environment [Second Case]

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
			FLEX(F_{B2},F_M)	COST (C_B,C_M)	FLEX (F_{B2},F_M)	COST (C_B,C_M)
MANUFACTURER DETERMINES FOR 2^{ND} BUYER	DECENTRALIZED	FIRST BUYER		(H,*) (L,*)		(H,*) (L,*)
		SECOND BUYER	(T,*) (L,*)	(H,*) (L,*)	(T,*) (L,*)	(H,*) (L,*)
		MANUFACTURER	(T,T) (T,L) (L,T) (L,L)	(H,H) (L,H) (H,L) (L,L)	(T,T) (T,L) (L,T) (L,L)	(H,H) (L,H) (H,L) (L,L)

* represents all different levels of the manufacturer

For the first buyer in her separate solution, there is no FLEX factor taken into account, since she is provided only loose FLEX level. In high DEVAR, she is indifferent in the COST levels, whereas in medium DEVAR, she has higher costs at high levels of COST due to less uncertainty calling for the small differences in quantities caused by the given loose FLEX level.

The second buyer has higher costs with respect to the first case, because this time, the manufacturer determines the parameters, which are stated in Table E.1 in Appendix E. She is provided tight and loose FLEX levels as presented in the previous chapter. In medium DEVAR, she has less average costs at loose level of FLEX. That is, her estimates fall within the bounds constructed by the flexibility parameters, meaning that she gets the benefit of the flexibility option provided. She is indifferent to both levels of COST at the two levels of DEVAR. According to the Tukey's test in the single factor model, in high DEVAR, the result indicates that she is indifferent to all combinations of FLEX and COST levels. But, the results according to the Duncan's test in the single factor model and to both tests in the multi factor model support the benefit gained due to the loose FLEX level by the second buyer whatever the COST level is. All single factor model results in the second case are presented in Appendix I.

Table 6.18 shows the different result of the Duncan's test from Tukey's test for the manufacturer in the decentralized environment

Table 6.18 Different Results of Duncan's Tests for the Manufacturer in the Decentralized Environment

DM Case	Environment	SC Actor	Medium DEVAR FLEX (F_{B2},F_M)
MANUFACTURER DETERMINES FOR 2ND BUYER	CENTRALIZED	MANUFACTURER	(T,T) (T,L) (L,T) (L,L)

The manufacturer in turn, has similar results as in the first case, where the DM is the second buyer. Although he determines the flexibility parameters; in high

DEVAR, he doesn't have differences in average costs as his incremental flexibility parameters get looser. Since the parameters are determined to satisfy a total cost limit, which is the optimal total cost of WCP obtained with the parameter decisions neglected, the flexibility parameters are not sufficient to provide him with lower average cost. However, in medium DEVAR, according to the results of Duncan's test applied in the multi factor model, which is presented in Table 6.18, the benefit gained by the manufacturer due to the manufacturer's loose FLEX is significant.

Similar to the first case results presented in Table 6.14, the high level of COST absolutely results in high costs, at both DEVAR levels. Although the inventory carrying and subcontracting costs gets high, the buyers do not change their amounts of replenishments requested from the manufacturer, since they act all independently from their own interests' perspective.

In the integrated supply chain, the SC actors are concerned with all combinations of the levels of FLEX and COST factors at a particular DEVAR level. Although there is no loose or tight FLEX level distinction for the first buyer, in fact the loose and tight FLEX levels of the second buyer and of the manufacturer affect her.

The test results for SC actors in the centralized environment are presented in Table 6.19.

Table 6.19 Cost Rankings and Comparison of Differences for SC Actors in the Centralized Environment [Second Case]

DM Case	Environment	SC Actor	Medium DEVAR FLEX (F_{B2},F_M)	Medium DEVAR COST (C_B,C_M)	High DEVAR FLEX (F_{B2},F_M)	High DEVAR COST (C_B,C_M)
MANUFACTURER DETERMINES FOR 2ND BUYER	CENTRALIZED	FIRST BUYER	(T,T) (T,L) (L,L) (L,T)	(L,H) (H,H) (H,L) (L,L)	(L,T) (T,T) (T,L) (L,L)	(L,H) (H,H) (H,L) (L,L)
		SECOND BUYER	(T,L) (T,T) (L,T) (L,L)	(L,H) (H,L) (H,H) (L,L)	(T,L) (T,T) (L,L) (L,L) (L,T)	(L,H) (H,L) (H,H) (L,L)
		MANUFACTURER	(L,T) (L,L) (T,L) (T,T)	(H,H) (H,L) (L,H) (L,L)	(T,L) (L,T) (T,T) (L,L)	(H,H) (L,H) (H,L) (L,L)

Unmatching results of Duncan's test for the SC actors in the integrated supply chain are presented in Table 6.20.

Table 6.20 Different Results of Duncan's Tests for the SC Actors in the Centralized Environment [Second Case]

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
			FLEX (F_{B2},F_M)	COST (C_B,C_M)	FLEX (F_{B2},F_M)	COST (C_B,C_M)
MANUFACTURER DETERMINES FOR 2ND BUYER	CENTRALIZED	FIRST BUYER	(T,T) (T,L) (T,L) (L,L) (L,L) (L,T)	(L,H) (H,H) (H,H) (H,L) (H,L) (L,L)	(L,T) (T,T) (T,T) (T,L) (T,L) (L,L)	(L,H) (H,H) (H,L) (H,L) (L,L)
		SECOND BUYER			(T,L) (T,T) (T,T) (L,L) (L,L) (L,T)	
		MANUFACTURER				(H,H) (L,H) (H,L) (H,L) (L,L)

When the test results at both DEVAR levels are examined, it is observed that the tight FLEX level of the manufacturer gives burden onto the first buyer. Also, when this level is taken into account alone, it is seen that the loose FLEX level of the second buyer also makes her cost higher. On the other hand, upon the loose FLEX level of the manufacturer, the loose FLEX level of the second buyer grants benefit to the first buyer since they are on the same side, i.e., they both request replenishment from the manufacturer. Since the benefit arising from the loose FLEX level of the manufacturer is directed to buyers in order to improve the systemwide performance, when the second buyer is provided with loose FLEX level, the first buyer also gets benefit from her loose FLEX level.

In high DEVAR, the first buyer has the highest average cost at the cost combination $(C_B,C_M)=(L,H)$ as in the first case. However, other (C_B,C_M) combinations have unmatching outcomes in Tukey's and Duncan's tests. Tukey's test results in no different average costs for the cost combinations other than the $(C_B,C_M)=(L,H)$. Duncan's test says that the low COST level of the manufacturer yields significantly less average costs to the first buyer. In medium DEVAR, Tukey's test yields no difference for the average costs of the first buyer at all COST levels, whereas Duncan's test says the high COST level of the manufacturer results in significantly higher cost for the first buyer than the low COST level of him. The negative or positive effect of the manufacturer's cost is all due to trying to direct his cost burden onto the first buyer in order to make the system wide performance better. However, the tests results are not decisive due to less number of samples. Thus, lower error rate may be selected in determining the required sample size.

For the second buyer acting in integrated supply chain, the same results gathered for the first buyer in the first case are obtained. The second buyer gets the benefit as her flexibility parameters get looser while yielding better position not only for her part but also in the overall system at both DEVAR levels. Also at either DEVAR level, the $(C_B,C_M)=(L,H)$ combination gives the highest average cost on the second buyer as in the first buyer's case. The reasoning behind this result is that in order to reduce the subcontracting requirement due to the high subcontracting costs, the buyers are forced to backorder some amount of their customer demand just to improve the system wide performance. We also see that at high DEVAR level, the second buyer wants the manufacturer be tight in his plans, while she maintains a loose FLEX level. Since larger amount of the system wide cost is formed by the manufacturer's costs, she asks him to be tight and perform less subcontracting. In medium DEVAR, she gets the most benefit when both parties have loose FLEX levels due to less uncertainty, where the positive outcomes of flexibility usage can be more easily captured.

The manufacturer, who plays his game with the buyers in the integrated supply chain, is indifferent at all levels of FLEX at both DEVAR levels. Since he determines the flexibility parameters with a limited total cost constraint, and since the loose flexibility option is given to the first buyer at the beginning of the game, being indifferent among FLEX levels is expected. Then, it can be concluded that the system wide performance is based on the FLEX levels of the buyers, not of the manufacturer. In high DEVAR, since there is no way to reduce the total system cost, the highest average cost for the manufacturer occurs in the cost combination (C_B,C_M)=(H,H), as expected. On the other hand, in the high DEVAR, Duncan's test indicates that the cost combinations, {(L,H), (H,L)} and {(H,L), (L,L)} are not significantly different from each other, which means that his average cost can decrease when there is some possibility for cost substitution among the buyers and the manufacturer.

6.3.3 INDIVIDUAL versus INTEGRATED SUPPLY CHAIN ENVIRONMENTS (Decentralized versus Centralized Environments)

Apart from the analysis of the factor levels on the attitudes of the SC actors, and their underlying reasons in the individual and in the integrated supply chain environments, the roles in playing the supply chain game separately or all together are also investigated. In order to find out who wants to play on his own or who wants to cooperate with the other parties, a single factor model where the factor corresponds to being individual or being involved in the integrated supply chain is constructed. For all SC actors, the single factor model is built for each combination of FLEX and COST levels at a particular DEVAR level.

In the two cases, where the decision maker (DM) of the flexibility parameters for the second buyer is alternated, combinations in which the first buyer favors information asymmetry and in which she does not, are presented in Table 6.21 and 6.22. Favorable stands for support to be involved in the integrated supply chain, unfavorable means the opposite, and no difference indicates the means of the decentralized and centralized are not different.

Table 6.21 Decentralized versus Centralized Environments for the First Buyer in the First Case

2nd Buyer determines her flexibility parameters

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

FIRST BUYER			
FLEXIBILITY TIGHTNESS (F_{B1},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	-	o
	(L,H)	-	-
	(H,L)	-	o
	(H,H)	-	o
(T,L)	(L,L)	-	o
	(L,H)	-	-
	(H,L)	-	o
	(H,H)	-	o
(L,T)	(L,L)	-	-
	(L,H)	-	-
	(H,L)	-	-
	(H,H)	-	-
(L,L)	(L,L)	-	-
	(L,H)	-	-
	(H,L)	-	-
	(H,H)	-	-

*: favorable -: unfavorable o: no difference

As seen from the table, in the loose FLEX level, whether the first buyer has a high or low COST level, she would never like to be involved in the integrated supply chain at both DEVAR levels. Since risk increases at high DEVAR level, she tries to carry more inventory for the future periods. Also, as the discrete possible demand values are far apart from the forecast with this level of DEVAR, the chance of either backordering or carrying large inventory increases. Thus, at high DEVAR level, when she has tight FLEX level, she sometimes favors to be placed in the integrated supply chain. On the other hand, in medium DEVAR, the case where she is provided tight flexibility parameters, she has already got the advantage of flexibility options due to less variation of her demand forecasts.

Table 6.22 Decentralized versus Centralized Environments for the First Buyer in the Second Case

Manufacturer determines the flexibility parameters to be offered to the second buyer
DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

FIRST BUYER			
FLEXIBILITY TIGHTNESS (F_{B1},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	-	-
	(L,H)	-	-
	(H,L)	-	-
	(H,H)	-	-
(T,L)	(L,L)	-	-
	(L,H)	-	-
	(H,L)	-	-
	(H,H)	-	-
(L,T)	(L,L)	-	-
	(L,H)	-	-
	(H,L)	-	-
	(H,H)	-	-
(L,L)	(L,L)	-	-
	(L,H)	-	-
	(H,L)	-	-
	(H,H)	-	-

*: favorable -: unfavorable o: no difference

In this case, since she is provided loose FLEX level all the time, at both DEVAR levels, she always favors to behave independently.

The second buyer's choices for being involved in the integrated supply chain, in the two cases are shown in Table 6.23 and 6.24.

Table 6.23 Decentralized versus Centralized Environments for the Second Buyer in the First Case

2nd Buyer determines her flexibility parameters
DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

SECOND BUYER			
FLEXIBILITY TIGHTNESS (F_{B1},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	o	o
	(L,H)	-	-
	(H,L)	o	o
	(H,H)	o	o
(T,L)	(L,L)	o	o
	(L,H)	-	-
	(H,L)	o	o
	(H,H)	o	o
(L,T)	(L,L)	o	o
	(L,H)	-	-
	(H,L)	o	-
	(H,H)	o	-
(L,L)	(L,L)	o	o
	(L,H)	-	-
	(H,L)	o	o
	(H,H)	o	o

*: favorable -: unfavorable o: no difference

Since the second buyer determines her flexibility parameters while minimizing her inventory carrying and backordering costs; most of the time, she is indifferent in behaving independently or not, at both DEVAR levels. She favors being isolated at the cost combination (C_B,C_M) = (L,H). Because in the integrated supply chain, the cost burden of the manufacturer is always directed to the buyers. Apart from the particular cost combination, in high DEVAR, when she has loose level of FLEX and the manufacturer has tight level of FLEX at (C_B,C_M)=(H,L) and (H,H), she is again willing to behave independently, due to her high level of COST. In her decentralized environment, she pays not too much for the high COST level, although in the coordinated one, she pays more in order to make the overall system benefit.

Table 6.24 Decentralized versus Centralized Environments for the Second Buyer in the Second Case

Manufacturer determines the flexibility parameters to be offered to the second buyer
DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

SECOND BUYER			
FLEXIBILITY TIGHTNESS (F_{B1},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	o	o
	(L,H)	-	-
	(H,L)	o	-
	(H,H)	o	o
(T,L)	(L,L)	o	o
	(L,H)	-	-
	(H,L)	o	-
	(H,H)	o	o
(L,T)	(L,L)	o	-
	(L,H)	-	-
	(H,L)	o	-
	(H,H)	o	-
(L,L)	(L,L)	o	-
	(L,H)	-	-
	(H,L)	o	-
	(H,H)	o	-

*: favorable -: unfavorable o: no difference

When she is offered the flexibility parameters determined by the manufacturer, she is again indifferent to being involved in the integrated supply chain or not, except in the cost combination of (C_B,C_M)=(L,H), with medium DEVAR. This indicates that the manufacturer in fact offers sufficiently appealing contract parameters. At high DEVAR level, she does not want to play all together, because she is willing to use the advantage provided by the loose FLEX level, and not to pay the cost burden of the manufacturer to put the system in a better position.

However, when she has tight FLEX, either with the cost burden given to both sides, (H,H) or with low setting to all, (L,L); she is again indifferent at high DEVAR level. This indicates that the COST level being different between the two sides does not favor her to be involved in the centralized environment. That is, she gets the advantage of her appealing contract parameters, when the costs are not different.

The manufacturer's incentives related to behaving individually or not, in the two different cases are similar to each other. Thus, the results are displayed together in Table 6.25.

Table 6.25 Decentralized versus Centralized Environments for the Manufacturer in the First and Second Cases

2nd Buyer determines her flexibility parameters
Manufacturer determines the flexibility parameters to be offered to the second buyer
DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

MANUFACTURER			
FLEXIBILITY TIGHTNESS (F_{Bb},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	*	*
(T,L)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	*	*
(L,T)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	*	*
(L,L)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	*	*

*: favorable -: unfavorable o: no difference
For the first case, b=1 ; For the second case, b=2

As seen from the table, the manufacturer always wants to be involved in the integrated supply chain. He would rather know every medium and short term decisions of the buyers, and inform them what they request will cost to him directly, i.e., subcontracting costs, to them and the overall system. Since he can know the intended future replenishments, i.e., the internal self plans of the buyers; instead of planning according to his own replenishment forecasts, management of his capacity usage and subcontracting decisions according to the intended future replenishment amounts will definitely favor him.

Different from the costs of the SC actors, the total system cost is also statistically analyzed to examine whether to act in the decentralized or in the centralized manner improves the overall system benefit. For the analysis, the models are run based on each combination of the FLEX and COST levels at a particular DEVAR level.

The tests results according to the two cases where the decision maker of the flexibility parameters for the second buyer are different are presented in Table 6.26 and 6.27.

Table 6.26 Decentralized versus Centralized Environments for the Overall System in the First Case

2nd Buyer determines her flexibility parameters

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

OVERALL SYSTEM			
FLEXIBILITY TIGHTNESS (F_{B1},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	*	*
(T,L)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	*	*
(L,T)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	o	o
(L,L)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	*	*
	(H,H)	o	o

*: favorable   -: unfavorable   o: no difference

When the second buyer determines the flexibility parameters not considering the others, it easily detected that, involving all SC actors into the supply chain game, always favors the overall system benefit, except the cost combination (C_B,C_M)=(H,H) upon the flexibility tightness combinations (F_B,F_M)={(L,T), (L,L)}. The reason for the exception is that there is no way to reduce the overall cost, when the cost burden is given to all the parties. The flexibility tightness exception stems from the fact that the COST effect outweighs the FLEX effect. Although, the buyers get the benefit of loose FLEX level, the manufacturer's resulting cost offset their advantages. The lesson from this is to enquire about the sources of costs to reap the benefits of coordinated activity.

Table 6.27 Decentralized versus Centralized Environments for the Overall System in the Second Case

Manufacturer determines the flexibility parameters to be offered to the second buyer
DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

OVERALL SYSTEM			
FLEXIBILITY TIGHTNESS (F_{B2},F_M)	COST (C_B,C_M)	Medium DEVAR	High DEVAR
(T,T)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	o	*
	(H,H)	o	*
(T,L)	(L,L)	*	*
	(L,H)	*	*
	(H,L)	o	o
	(H,H)	o	*
(L,T)	(L,L)	o	*
	(L,H)	*	*
	(H,L)	o	*
	(H,H)	o	*
(L,L)	(L,L)	o	*
	(L,H)	*	*
	(H,L)	o	*
	(H,H)	o	*

*: favorable   -: unfavorable   o: no difference

When the manufacturer determines the flexibility parameters to be offered to the second buyer, the overall system's choice to involve all SC actors into the supply chain game changes dramatically. Since the major part of the system cost is comprised of the manufacturer's inventory carrying and subcontracting cost, being the DM makes the system behave like him, i.e., favoring integrated supply chain, especially in high DEVAR. However, in medium DEVAR, at the cost combinations (C_B,C_M)={(H,H), (H,L)}, the overall system is indifferent to the choice. Although the buyers favor to be independent, i.e., in a decentralized manner; in medium DEVAR, the high COST level of the manufacturer results in such a high cost that the overall system cost gets high as in the integrated supply chain. Thus, due to less variation, the system can not make itself better though information is fully shared. Moreover, at the (H,L) combination, larger subcontracting amounts are realized due to high unit cost of backordering in the centralized environment. In the decentralized environment, though the high backordering cost doesn't yield high costs for the buyers, the subcontracting costs raised by the requested replenishment amounts cause the overall system be indifferent in individual and integrated supply chain environments. Whereas in high DEVAR, it can put itself in a better position by involving all in a single game, since it has room to make possible adjustments in cost substitution among SC actors such as using the flexibility options more efficiently. That is, the higher the risk is, the more effectively the option is exploited.

CHAPTER VII

CONCLUSION

Demand forecast and volatility, inventory carrying, backordering, and subcontracting costs, risk tolerance, capacity reservation, lead times are the drivers that impact supply contracts

In this study, we aim to present a structure for the analysis of the incentives of a buyer who is offered a Quantity Flexibility (QF) contract by a manufacturer having a working QF contract with another buyer.

A QF contract is an arrangement that forces the parties plan more deliberately to make the performance of not only theirs but also the overall system better. In this particular type of contract, the buyer commits not to purchase less than a certain percentage ω below her estimate and the manufacturer guarantees to release up to a certain percentage α above her estimate. This feature of QF contract provides some challenging effects such as less amount of inventory carried or demand backordered.

In this particular study, although the manufacturer has no relation with an upstream supplier, he is treated as if he has a QF contract with himself. The aim is to provide a QF environment to the manufacturer to manage his medium and short term decisions with more control and deliberation.

The two buyers serve to their own markets and the manufacturer supplies the same item to both buyers. All parties have their own forecast information with some inaccuracy. Only the realized requirement for the current period and the replenishment schedules for both buyers are informed to the manufacturer. The manufacturer involved into the supply chain picture is given a limited capacity, but also provided with two subcontracting options of different lead times.

The market demands and the actual replenishment amounts that the buyers and the manufacturer face, are not deterministic. Hence, the models constructed for all parties with the objective of cost minimization turns out to be stochastic models. In the formulation of these stochastic models, a scenario based approach is utilized. In these models, some decision variables are independent and some are dependent on the realizations of the random variables. The former ones are called "here and now" decisions, and the latter ones are called "wait and see" decisions. The model is divided into two stages, where the independent and the dependent decision variables are in the first and second stages, respectively. The two-stage stochastic models of all parties are solved using Benders Decomposition algorithm.

We analyze the attitudes of the SC actors in both the individual and the integrated supply chain environments, where there is no information asymmetry in the latter. For the analysis, three factors are decided to apply, which are demand variation, DEVAR, flexibility tightness, FLEX, and cost, COST. The values of these particular factor levels are determined with the approach of being at the reasonable minimum and maximum extremes.

Moreover, two main cases related to the second buyer are generated. In the first case, the decision maker (DM) of the flexibility parameters to be used by the second buyer is herself, whereas in the second case the DM is the manufacturer. According to these two cases, at different factor levels, the incentives of all SC actors in their individual, i.e., decentralized and in the integrated supply chain, i.e., centralized environments are questioned.

For the analysis some samples are taken from the possible scenarios generated which are not identical for the buyers and the manufacturer. According to the results of these samples, multiple comparisons are carried out by utilizing the statistical software, SAS, with the multiple test options it provides. The Tukey's and Duncan's tests are applied for the comparisons, where the former evaluates the Type I experiment wise error rate, and the latter, comparison wise error rate.

In accordance with the multiple test results, it can be concluded that in the first case, the second buyer is indifferent to behave independently or be involved in the integrated supply chain due to being the DM of her flexibility parameters. That is, she gets the advantage of the flexibility option provided by the QF contract. In the second case, she is mostly indifferent in medium DEVAR, indicating that the flexibility parameters offered to her are sufficiently appealing. However, in high DEVAR, she favors begin independent due to increasing uncertainty.

In both cases, the first buyer often favors being alone in the QF environment. Since she is given the flexibility parameters beforehand, she always exploits the flexibility option provided when she is on her own. However, when she is involved into the integrated supply chain, she is always given the cost burden of the manufacturer and sometimes of the second buyer, too.

Moreover, at either DEVAR levels, the cost combination $(C_B,C_M)=(L,H)$ gives the highest cost for the two buyers in the centralized environment. This is due to the high cost of subcontracting. Since the aim is to improve the systemwide performance, in order not to give larger orders to the subcontractor, the buyers are forced to backorder some amount of their customer demand. Since the high COST of the manufacturer results in high average costs for him and the integrated SC, when a cost reduction program is activated, it should start at the manufacturer.

However, the manufacturer is willing to be involved in the integrated supply chain all the time and in all different environmental factors. This typical behavior is due to the limited capacity, and the expensive subcontracting option. Especially, as the demand variation increases, i.e., uncertainty increases, the willingness to have the information of the others' decisions and to inform others of his, increases.

Less variation in the replenishment forecasts, i.e., medium DEVAR yields in less subcontracting, less inventory carried for the future periods, and high capacity utilization. This is also achieved by the loose FLEX of the buyers resulting less replenishment amounts requested from him. Thus, the manufacturer gets into a better position in his individual environment, when the buyers also get the benefit of loose FLEX and low COST, and then request less. However, the marginal improvement is not as big as the one in the integrated supply chain. Since the manufacturer has a limited capacity, i.e., he has a restricted environment, he has to do subcontracting. Some part of the cost of this compulsion can be directed to others in the integrated supply chain environment which results in less cost than in his individual environment.

It is also observed that in some cases, the limited capacity of the manufacturer is not utilized in full. Due to the intention to cover all forecasted replenishments, larger amounts are ordered to the subcontractor. When a relatively less replenishment amount is realized, the excess subcontracting amount arrives regardless of the actual need which reduces the capacity utilization.

Another characteristic result is that as the demand variation increases, the values of the flexibility parameters of the second buyer increase in both cases. This indicates that as uncertainty increases, the willingness to have more flexibility option and worth of flexibility increase in order to offset the variation effect by the opportunities provided.

Moreover, when the DM is the manufacturer, the system model often suggests similar decisions as to being independent or not, as the manufacturer. Due to being the creator of the environment characteristics, the system behaves like him.

Furthermore, in medium DEVAR, the positive outcomes of the flexibility usage can be more easily captured due to lower uncertainty, i.e., less possibility for the realizations of large and small demands or replenishments. It can also be concluded that the system wide performance is mostly based on the FLEX levels of the buyers, not of the manufacturer in both cases.

Additionally, although the buyers favor to be independent, i.e., in a decentralized manner; in medium DEVAR; the high COST level of the manufacturer results in such a high cost that the overall system cost gets high as in the integrated supply chain. Thus, due to less variation, the system can not make itself better though information is fully shared. Whereas in high DEVAR, it can put itself in a better position in the centralized environment due to information sharing and control. That is, the higher the risk is, the more effectively the option is exploited for the overall system.

It is also observed that information sharing gives benefit to the overall system most of the time. This also indicates that apart from the involvers of the QF contract who are the buyers and the manufacturer, also the customers can take a part in the contracts, so that more accurate information will be gathered, which will definitely improve the system.

In this study, the stochastic random variables are assumed to have discrete distributions to avoid nonlinearities. As a future research, they can be assumed to have continuous distributions, and instead of struggling with the nonlinearities, some heuristic approaches can be generated.

Another future research direction can be the analysis of the limited capacity amount and trying to figure out at which level, the manufacturer can exploit the flexibility option while taking the buyers' choices into account. Also, the tradeoff between having a limited capacity and investing for the expansion of the restricted capacity can be investigated.

Moreover, what rations the limited capacity of the manufacturer, the effect of the flexibility given for each buyer on the capacity allocation, and ways to coordinate for the limited capacity can be the possible future research questions.

Game theoretic approaches may be applied between the two buyers and between one buyer and the manufacturer to analyze the attitudes and the possible negotiations opportunities. Also the buyers can incorporate within each other by informing some part of their decisions to the other one to utilize the limited capacity, and hence improve the performance of both.

Finally, for continuous probability distributions, Monte Carlo sampling and Gaussian quadrature, which are the two most commonly used discreatization stragtegies can be applied for the probability space for approximating the multivariate probability integrals.

Moreover, some comparison test results do not agree, i.e., are inconclusive to decide which factor affects the others or the reasoning underlying the consequences. To overcome the indecisiveness of the test results, sample size can be increased for the analysis. That is, the error rate in selecting the required sample size may be decreased as a future research.

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APPENDIX A

DEMAND DATA GENERATED FOR THE FIRST AND SECOND BUYERS IN MEDIUM ANG HIGH DEVAR

Table A.1 Demand Data Generated for the First Buyer in Medium DEVAR

1ST BUYER	**MEDIUM DEVAR**			Discrete Values	Probabilities
1ST PERIOD	**500**	2ND PERIOD		605	0.3
				495	0.1
				575	0.2
				510	0.4
			MEAN	**550**	
		3RD PERIOD		660	0.2
				540	0.3
				520	0.1
				635	0.4
			MEAN	**600**	
		4TH PERIOD		615	0.3
				485	0.1
				585	0.2
				500	0.4
			MEAN	**550**	

2ND PERIOD		3RD PERIOD		660	0.2
				540	0.3
				560	0.1
				625	0.4
			MEAN	**600**	
		4TH PERIOD		605	0.3
				495	0.1
				595	0.2
				500	0.4
			MEAN	**550**	
		5TH PERIOD		660	0.2
	600			540	0.3
				500	0.1
				640	0.4
			MEAN	**600**	

1ST BUYER				Discrete Values	Probabilities
3RD PERIOD		4TH PERIOD		605	0.3
				495	0.1
				575	0.2
				510	0.4
			MEAN	**550**	
		5TH PERIOD		660	0.2
				540	0.3
				520	0.1
				635	0.4
			MEAN	**600**	
		6TH PERIOD		615	0.3
	550			485	0.1
				585	0.2
				500	0.4
			MEAN	**550**	

4TH PERIOD		5TH PERIOD		660	0.2
				540	0.3
				560	0.1
				625	0.4
			MEAN	**600**	
		6TH PERIOD		605	0.3
				495	0.1
				595	0.2
				500	0.4
			MEAN	**550**	
		7TH PERIOD		555	0.1
	500			445	0.3
				455	0.2
				550	0.4
			MEAN	**500**	

Table A.2 Demand Data Generated for the Second Buyer in Medium DEVAR

2ND BUYER	**MEDIUM DEVAR**			Discrete Values	Probabilities
1ST PERIOD		2ND PERIOD		660	0.2
	600			540	0.3
				560	0.1
				625	0.4
			MEAN	**600**	
		3RD PERIOD		725	0.3
	650			585	0.2
				695	0.1
				615	0.4
			MEAN	**650**	
		4TH PERIOD		660	0.2
	600			540	0.3
				500	0.1
				640	0.4
			MEAN	**600**	

2ND PERIOD		3RD PERIOD		715	0.3
	650			585	0.2
				685	0.1
				625	0.4
			MEAN	**650**	
		4TH PERIOD		660	0.2
	600			540	0.3
				520	0.1
				635	0.4
			MEAN	**600**	
		5TH PERIOD		735	0.3
	650			585	0.2
				705	0.1
				605	0.4
			MEAN	**650**	

2ND BUYER				Discrete Values	Probabilities
3RD PERIOD		4TH PERIOD		660	0.2
	600			540	0.3
				560	0.1
				625	0.4
			MEAN	**600**	
		5TH PERIOD		725	0.3
	650			585	0.2
				695	0.1
				615	0.4
			MEAN	**650**	
		6TH PERIOD		660	0.2
	600			540	0.3
				500	0.1
				640	0.4
			MEAN	**600**	

4TH PERIOD		5TH PERIOD		715	0.3
	650			585	0.2
				685	0.1
				625	0.4
			MEAN	**650**	
		6TH PERIOD		660	0.2
	600			540	0.3
				520	0.1
				635	0.4
			MEAN	**600**	
		7TH PERIOD		615	0.3
	550			485	0.1
				585	0.2
				500	0.4
			MEAN	**550**	

Table A.3 Demand Data Generated for the First Buyer in high DEVAR

1ST BUYER	**HIGH DEVAR**			Discrete Values	Probabilities
1ST PERIOD	**500**	2ND PERIOD		660	0.3
	550			440	0.1
				600	0.2
				470	0.4
			MEAN	**550**	
		3RD PERIOD		720	0.2
	600			460	0.3
				540	0.1
				660	0.4
			MEAN	**600**	
		4TH PERIOD		660	0.3
	550			440	0.1
				630	0.2
				455	0.4
			MEAN	**550**	

2ND PERIOD		3RD PERIOD		720	0.2
				480	0.3
				520	0.1
				650	0.4
			MEAN	**600**	
		4TH PERIOD		660	0.3
				440	0.1
				620	0.2
				460	0.4
			MEAN	**550**	
		5TH PERIOD		720	0.2
	600			460	0.3
				520	0.1
				665	0.4
			MEAN	**600**	

1ST BUYER				Discrete Values	Probabilities
3RD PERIOD		4TH PERIOD		660	0.3
				440	0.1
				600	0.2
				470	0.4
			MEAN	**550**	
		5TH PERIOD		720	0.2
				460	0.3
				540	0.1
				660	0.4
			MEAN	**600**	
		6TH PERIOD		660	0.3
	550			440	0.1
				630	0.2
				455	0.4
			MEAN	**550**	

4TH PERIOD		5TH PERIOD		720	0.2
				480	0.3
				520	0.1
				650	0.4
			MEAN	**600**	
		6TH PERIOD		660	0.3
				440	0.1
				620	0.2
				460	0.4
			MEAN	**550**	
		7TH PERIOD		600	0.1
	500			400	0.3
				420	0.2
				590	0.4
			MEAN	**500**	

Table A.4 Demand Data Generated for the Second Buyer in High DEVAR

2ND BUYER	**HIGH DEVAR**			Discrete Values	Probabilities
1ST PERIOD		2ND PERIOD		720	0.2
	600			480	0.3
				520	0.1
				650	0.4
			MEAN	**600**	
		3RD PERIOD		800	0.3
	650			520	0.2
				700	0.1
				590	0.4
			MEAN	**650**	
		4TH PERIOD		720	0.2
	600			460	0.3
				520	0.1
				665	0.4
			MEAN	**600**	

2ND PERIOD		3RD PERIOD		780	0.3
	650			520	0.2
				740	0.1
				595	0.4
			MEAN	**650**	
		4TH PERIOD		720	0.2
	600			460	0.3
				540	0.1
				660	0.4
			MEAN	**600**	
		5TH PERIOD		800	0.3
	650			520	0.2
				760	0.1
				575	0.4
			MEAN	**650**	

2ND BUYER				Discrete Values	Probabilities
3RD PERIOD		4TH PERIOD		720	0.2
				480	0.3
				520	0.1
				650	0.4
			MEAN	**600**	
		5TH PERIOD		800	0.3
				520	0.2
				700	0.1
				590	0.4
			MEAN	**650**	
		6TH PERIOD		720	0.2
	600			460	0.3
				520	0.1
				665	0.4
			MEAN	**600**	

4TH PERIOD		5TH PERIOD		780	0.3
	650			520	0.2
				740	0.1
				595	0.4
			MEAN	**650**	
		6TH PERIOD		720	0.2
	600			460	0.3
				540	0.1
				660	0.4
			MEAN	**600**	
		7TH PERIOD		660	0.3
	550			440	0.1
				630	0.2
				455	0.4
			MEAN	**550**	

APPENDIX B

DEMAND DATA GENERATED FOR THE MANUFACTURER IN MEDIUM AND HIGH DEVAR

Table B.1 Demand Data Generated for the Manufacturer in Medium DEVAR

MANUFACTURER FOR **1ST BUYER**			**MEDIUM DEVAR**	Discrete Values	Probabilities
1ST PERIOD		2ND PERIOD		605	0.2
	550			495	0.3
				525	0.1
				570	0.4
			MEAN	**550**	
		3RD PERIOD		660	0.3
	600			540	0.1
				550	0.4
				640	0.2
			MEAN	**600**	
		4TH PERIOD		605	0.2
	550			475	0.3
				505	0.1
				590	0.4
			MEAN	**550**	

MANUFACTURER FOR **2ND BUYER**				Discrete Values	Probabilities
1ST PERIOD		2ND PERIOD		660	0.3
	600			540	0.1
				560	0.4
				620	0.2
			MEAN	**600**	
		3RD PERIOD		715	0.1
	650			585	0.3
				595	0.2
				710	0.4
			MEAN	**650**	
		4TH PERIOD		660	0.3
	600			530	0.1
				545	0.4
				655	0.2
			MEAN	**600**	

MANUFACTURER FOR **1ST BUYER**			Discrete Values	Probabilities
2ND PERIOD	3RD PERIOD		660	0.3
			540	0.1
			560	0.4
			620	0.2
		MEAN	**600**	
	4TH PERIOD		605	0.2
			485	0.3
			495	0.1
			585	0.4
		MEAN	**550**	
	5TH PERIOD		660	0.3
600			530	0.1
			545	0.4
			655	0.2
		MEAN	**600**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
2ND PERIOD	3RD PERIOD		715	0.1
			585	0.3
			615	0.2
			700	0.4
		MEAN	**650**	
	4TH PERIOD		660	0.3
			540	0.1
			550	0.4
			640	0.2
		MEAN	**600**	
	5TH PERIOD		725	0.1
650			565	0.3
			630	0.2
			705	0.4
		MEAN	**650**	

MANUFACTURER FOR **1ST BUYER**			Discrete Values	Probabilities
3RD PERIOD	4TH PERIOD		605	0.2
			495	0.3
			525	0.1
			570	0.4
		MEAN	**550**	
	5TH PERIOD		660	0.3
			540	0.1
			550	0.4
			640	0.2
		MEAN	**600**	
	6TH PERIOD		605	0.2
550			475	0.3
			505	0.1
			590	0.4
		MEAN	**550**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
3RD PERIOD	4TH PERIOD		660	0.3
			540	0.1
			560	0.4
			620	0.2
		MEAN	**600**	
	5TH PERIOD		715	0.1
			585	0.3
			595	0.2
			710	0.4
		MEAN	**650**	
	6TH PERIOD		660	0.3
600			530	0.1
			545	0.4
			655	0.2
		MEAN	**600**	

MANUFACTURER FOR **1ST BUYER**			Discrete Values	Probabilities
4TH PERIOD	5TH PERIOD		660	0.3
			540	0.1
			560	0.4
			620	0.2
		MEAN	**600**	
	6TH PERIOD		605	0.2
			485	0.3
			495	0.1
			585	0.4
		MEAN	**550**	
	7TH PERIOD		565	0.3
500			420	0.2
			485	0.1
			495	0.4
		MEAN	**500**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
4TH PERIOD	5TH PERIOD		715	0.1
			585	0.3
			615	0.2
			700	0.4
		MEAN	**650**	
	6TH PERIOD		660	0.3
			540	0.1
			550	0.4
			640	0.2
		MEAN	**600**	
	7TH PERIOD		605	0.2
550			475	0.3
			505	0.1
			590	0.4
		MEAN	**550**	

Table B.2 Demand Data Generated for the Manufacturer in High DEVAR

MANUFACTURER FOR **1ST BUYER**		**HIGH DEVAR**	Discrete Values	Probabilities
1ST PERIOD	2ND PERIOD		660	0.2
550			440	0.3
			480	0.1
			595	0.4
		MEAN	**550**	
	3RD PERIOD		720	0.3
600			480	0.1
			505	0.4
			670	0.2
		MEAN	**600**	
	4TH PERIOD		660	0.2
550			420	0.3
			460	0.1
			615	0.4
		MEAN	**550**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
1ST PERIOD	2ND PERIOD		720	0.3
600			480	0.1
			515	0.4
			650	0.2
		MEAN	**600**	
	3RD PERIOD		780	0.1
650			520	0.3
			580	0.2
			750	0.4
		MEAN	**650**	
	4TH PERIOD		720	0.3
600			480	0.1
			500	0.4
			680	0.2
		MEAN	**600**	

MANUFACTURER FOR **1ST BUYER**			Discrete Values	Probabilities
2ND PERIOD	3RD PERIOD		720	0.3
600			480	0.1
			515	0.4
			650	0.2
		MEAN	**600**	
	4TH PERIOD		660	0.2
550			420	0.3
			500	0.1
			605	0.4
		MEAN	**550**	
	5TH PERIOD		720	0.3
600			480	0.1
			500	0.4
			680	0.2
		MEAN	**600**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
2ND PERIOD	3RD PERIOD		780	0.1
650			520	0.3
			600	0.2
			740	0.4
		MEAN	**650**	
	4TH PERIOD		720	0.3
600			480	0.1
			505	0.4
			670	0.2
		MEAN	**600**	
	5TH PERIOD		780	0.1
650			520	0.3
			560	0.2
			760	0.4
		MEAN	**650**	

MANUFACTURER FOR **1ST BUYER**			Discrete Values	Probabilities
3RD PERIOD	4TH PERIOD		660	0.2
550			440	0.3
			480	0.1
			595	0.4
		MEAN	**550**	
	5TH PERIOD		720	0.3
600			480	0.1
			505	0.4
			670	0.2
		MEAN	**600**	
	6TH PERIOD		660	0.2
550			420	0.3
			460	0.1
			615	0.4
		MEAN	**550**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
3RD PERIOD	4TH PERIOD		720	0.3
600			480	0.1
			515	0.4
			650	0.2
		MEAN	**600**	
	5TH PERIOD		780	0.1
650			520	0.3
			580	0.2
			750	0.4
		MEAN	**650**	
	6TH PERIOD		720	0.3
600			480	0.1
			500	0.4
			680	0.2
		MEAN	**600**	

MANUFACTURER FOR **1ST BUYER**			Discrete Values	Probabilities
4TH PERIOD	5TH PERIOD		720	0.3
600			480	0.1
			515	0.4
			650	0.2
		MEAN	**600**	
	6TH PERIOD		660	0.2
550			420	0.3
			500	0.1
			605	0.4
		MEAN	**550**	
	7TH PERIOD		620	0.3
500			400	0.2
			580	0.1
			440	0.4
		MEAN	**500**	

MANUFACTURER FOR **2ND BUYER**			Discrete Values	Probabilities
4TH PERIOD	5TH PERIOD		780	0.1
650			520	0.3
			600	0.2
			740	0.4
		MEAN	**650**	
	6TH PERIOD		720	0.3
600			480	0.1
			505	0.4
			670	0.2
		MEAN	**600**	
	7TH PERIOD		660	0.2
550			420	0.3
			460	0.1
			615	0.4
		MEAN	**550**	

APPENDIX C

SAMPLES GENERATED FOR THE SUPPLY CHAIN ACTORS AND INTEGRATED SUPPLY CHAIN IN MEDIUM AND HIGH DEVAR

Table C.1 Samples Generated for the Supply Chain Actors and Integrated Supply Chain in Medium DEVAR

First Buyer		1st Period	2nd Period	3rd Period	4th Period
1st Sample		500.0	495.0	660.0	510.0
2nd Sample		500.0	510.0	625.0	495.0
3rd Sample		500.0	605.0	560.0	510.0

Second Buyer		1st Period	2nd Period	3rd Period	4th Period
1st Sample		550.0	540.0	685.0	540.0
2nd Sample		550.0	660.0	685.0	560.0
3rd Sample		550.0	560.0	625.0	660.0

Manufacturer		1st Period	2nd Period	3rd Period	4th Period
1st Sample	First Buyer	500.0	605.0	597.1	513.8
	Second Buyer	550.0	600.0	650.0	515.0
2nd Sample	First Buyer	500.0	547.4	587.6	547.4
	Second Buyer	550.0	600.0	650.0	595.0

Integrated Supply Chain					
		1st Period	2nd Period	3rd Period	4th Period
1st Sample	First Buyer	500.0	605.0	560.0	510.0
	Second Buyer	550.0	540.0	685.0	540.0
2nd Sample	First Buyer	500.0	510.0	625.0	495.0
	Second Buyer	550.0	560.0	625.0	660.0
3rd Sample	First Buyer	500.0	495.0	660.0	510.0
	Second Buyer	550.0	660.0	685.0	560.0

Table C.2 Samples Generated for the Supply Chain Actors and Integrated Supply Chain in High DEVAR

First Buyer				
	1st Period	2nd Period	3rd Period	4th Period
1st Sample	500.0	660.0	720.0	470.0
2nd Sample	500.0	660.0	480.0	600.0
3rd Sample	500.0	660.0	650.0	470.0
4th Sample	500.0	440.0	480.0	470.0
5th Sample	500.0	440.0	650.0	440.0
6th Sample	500.0	600.0	720.0	440.0
7th Sample	500.0	600.0	720.0	600.0
8th Sample	500.0	600.0	650.0	470.0
9th Sample	500.0	470.0	520.0	470.0

Second Buyer				
	1st Period	2nd Period	3rd Period	4th Period
1st Sample	550.0	720.0	780.0	520.0
2nd Sample	550.0	720.0	520.0	650.0
3rd Sample	550.0	720.0	740.0	720.0
4th Sample	550.0	480.0	780.0	650.0
5th Sample	550.0	480.0	520.0	650.0
6th Sample	550.0	520.0	780.0	650.0
7th Sample	550.0	520.0	740.0	650.0
8th Sample	550.0	650.0	780.0	650.0
9th Sample	550.0	650.0	740.0	720.0

Manufacturer					
		1st Period	2nd Period	3rd Period	4th Period
1st Sample	First Buyer	500.0	612.5	714.5	622.7
	Second Buyer	550.0	720.0	650.0	520.0
2nd Sample	First Buyer	500.0	612.5	646.5	552.2
	Second Buyer	550.0	720.0	740.0	719.9
3rd Sample	First Buyer	500.0	612.5	697.9	597.1
	Second Buyer	550.0	600.0	660.0	650.0
4th Sample	First Buyer	500.0	553.9	573.3	529.5
	Second Buyer	550.0	600.0	700.0	650.0
5th Sample	First Buyer	500.0	553.9	573.3	541.0
	Second Buyer	550.0	600.0	650.0	400.0
6th Sample	First Buyer	500.0	600.0	714.5	597.1
	Second Buyer	550.0	650.0	740.0	719.9
7th Sample	First Buyer	500.0	600.0	714.5	605.5
	Second Buyer	550.0	650.0	780.0	650.0
8th Sample	First Buyer	500.0	600.0	650.0	595.4
	Second Buyer	550.0	720.0	780.0	520.0
9th Sample	First Buyer	500.0	553.9	573.3	529.5
	Second Buyer	550.0	600.0	660.0	650.0

Integrated Supply Chain					
		1st Period	2nd Period	3rd Period	4th Period
1st Sample	First Buyer	500.0	660.0	720.0	470.0
	Second Buyer	550.0	720.0	520.0	650.0
2nd Sample	First Buyer	500.0	660.0	480.0	600.0
	Second Buyer	550.0	720.0	740.0	720.0
3rd Sample	First Buyer	500.0	660.0	650.0	470.0
	Second Buyer	550.0	480.0	780.0	650.0
4th Sample	First Buyer	500.0	440.0	480.0	470.0
	Second Buyer	550.0	520.0	780.0	650.0
5th Sample	First Buyer	500.0	440.0	650.0	440.0
	Second Buyer	550.0	480.0	520.0	650.0
6th Sample	First Buyer	500.0	600.0	720.0	440.0
	Second Buyer	550.0	650.0	740.0	720.0
7th Sample	First Buyer	500.0	600.0	720.0	600.0
	Second Buyer	550.0	650.0	780.0	650.0
8th Sample	First Buyer	500.0	600.0	650.0	470.0
	Second Buyer	550.0	720.0	780.0	520.0
9th Sample	First Buyer	500.0	470.0	520.0	470.0
	Second Buyer	550.0	520.0	740.0	650.0

APPENDIX D

GAMS MODEL OF THE TWO-STAGE STOHASTIC PROGRAMMING MODEL OF THE FIRST BUYER

```
sets
t / 1, 2, 3, 4/
t3(t) / 2, 3, 4/
t2(t) / 4/
t1(t) / 1, 2, 3/
sc / 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29,
30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57,
58, 59, 60, 61, 62, 63, 64/;
parameter invprice
/1/;
parameter backprice
/3/;
parameter flexup(t3)
/2       1.05
 3       1.113
 4       1.191/;
parameter flexdown(t3)
/2       0.95
 3       0.893
 4       0.83/;
parameter RealizedDemand
/500/;
parameter inven
/0/;
parameter back
/0/;
parameter invens
/0/;
parameter backs
/0/;
parameter previousflexup(t1)
/1       525.000
 2       583.000
 3       642.000/;
parameter previousflexdown(t1)
/1       475.000
 2       517.000
 3       558.000/;
```

```
table dem(t3, sc)
        1       2       3       4       5       6       7       8       9       10      11      12      13      14
2       660     660     660     660     660     660     660     660     660     660     660     660     660     660
3       720     720     720     720     460     460     460     460     540     540     540     540     660     660
4       660     440     630     455     660     440     630     455     660     440     630     455     660     440

        15      16      17      18      19      20      21      22      23      24      25      26      27      28
2       660     660     440     440     440     440     440     440     440     440     440     440     440     440
3       660     660     720     720     720     720     460     460     460     460     540     540     540     540
4       630     455     660     440     630     455     660     440     630     455     660     440     630     455

        29      30      31      32      33      34      35      36      37      38      39      40      41      42
2       440     440     440     440     600     600     600     600     600     600     600     600     600     600
3       660     660     660     660     720     720     720     720     460     460     460     460     540     540
4       660     440     630     455     660     440     630     455     660     440     630     455     660     440

        43      44      45      46      47      48      49      50      51      52      53      54      55      56
2       600     600     600     600     600     600     470     470     470     470     470     470     470     470
3       540     540     660     660     660     660     720     720     720     720     460     460     460     460
4       630     455     660     440     630     455     660     440     630     455     660     440     630     455

        57      58      59      60      61      62      63      64
2       470     470     470     470     470     470     470     470
3       540     540     540     540     660     660     660     660
4       660     440     630     455     660     440     630     455;
```

```
parameter prob(sc)
/1       0.018          17      0.006          33      0.012          49      0.024
 2       0.006          18      0.002          34      0.004          50      0.008
 3       0.012          19      0.004          35      0.008          51      0.016
 4       0.024          20      0.008          36      0.016          52      0.032
 5       0.027          21      0.009          37      0.018          53      0.036
 6       0.009          22      0.003          38      0.006          54      0.012
 7       0.018          23      0.006          39      0.012          55      0.024
 8       0.036          24      0.012          40      0.024          56      0.048
 9       0.009          25      0.003          41      0.006          57      0.012
 10      0.003          26      0.001          42      0.002          58      0.004
 11      0.006          27      0.002          43      0.004          59      0.008
 12      0.012          28      0.004          44      0.008          60      0.016
 13      0.036          29      0.012          45      0.024          61      0.048
 14      0.012          30      0.004          46      0.008          62      0.016
 15      0.024          31      0.008          47      0.016          63      0.032
 16      0.048          32      0.016          48      0.032          64      0.064/;


variables                       positive variable
inv1(t)                         inv1
back1(t)                        back1
invs1(t,sc)                     invs1
backs1(t,sc)                    backs1
f0(t)                           f0
f1(t3)                          f1
f0s(t,sc)                       invs1
f1s(t2,sc)                      backs1
zWCP                            f0s
zSUB                            f1s;
zMASTER
M;
```

```
equations
cost define objective function of WCP
ucf(t3) upward cumulative flexibility constraints
dcf(t3) downward cumulative flexibility constraints
inve1 inventory balance constraint of the first period
inve2 inventory balance constraint of the second period
inve3 inventory balance constraint of the third period
inve4 inventory balance constraint of the fourth period
uif1 upward incremental flexiblity constraint of the first period
dif1 downward incremental flexiblity constraint of the first period
uif2 upward incremental flexiblity constraint of the second period
dif2 downward incremental flexiblity constraint of the second period
uif3 upward incremental flexiblity constraint of the third period
dif3 downward incremental flexiblity constraint of the third period;

cost..  zWCP =e= sum(t, invprice*inv1(t) + backprice*back1(t));

ucf(t3)..  f0(t3) =l= flexup(t3)*f1(t3);
dcf(t3)..  f0(t3) =g= flexdown(t3)*f1(t3);
inve1.. inv1('1') - back1('1') =e= inven - back + f0('1') - RealizedDemand;
inve2.. inv1('2') - back1('2') =e= inv1('1') - back1('1') + f0('2') - 660;
inve3.. inv1('3') - back1('3') =e= inv1('2') - back1('2') + f0('3') - 720;
inve4.. inv1('4') - back1('4') =e= inv1('3') - back1('3') + f0('4') - 660;
uif1.. f0('1') =l= previousflexup('1');
dif1.. f0('1') =g= previousflexdown('1');
uif2.. f1('2') =l= previousflexup('2');
dif2.. f1('2') =g= previousflexdown('2');
uif3.. f1('3') =l= previousflexup('3');
dif3.. f1('3') =g= previousflexdown('3');

model contract /cost, ucf, dcf, inve1, inve2, inve3, inve4, uif1, dif1, uif2, dif2, uif3, dif3 /;

solve contract using lp minimizing zWCP;
```

```
equations
cost2 define objective function of Sub Problem
inves1(sc) inventory balance constraint of the first period
inves2(sc) inventory balance constraint of the second period
inves3(sc) inventory balance constraint of the third period
inves4(sc) inventory balance constraint of the fourth period
ucfs2(sc) upward cumulative flexibility constraint of the second period
dcfs2(sc) downward cumulative flexibility constraint of the second period
ucfs3(sc) upward cumulative flexibility constraint of the third period
dcfs3(sc) downward cumulative flexibility constraint of the third period
ucfs4(sc) upward cumulative flexibility constraint of the fourth period
dcfs4(sc) downward cumulative flexibility constraint of the fourth period
uifs1(sc) upward incremental flexiblity constraint of the first period
difs1(sc) downward incremental flexiblity constraint of the first period
nonantci11 nonanticipativity constraints for inventory carried of first period
...
nonantci163 nonanticipativity constraints for inventory carried of first period
nonantci21 nonanticipativity constraints for inventory carried of second period
...
nonantci260 nonanticipativity constraints for inventory carried of second period
nonantci31 nonanticipativity constraints for inventory carried of third period
...
nonantci348 nonanticipativity constraints for inventory carried of third period
nonantcb11 nonanticipativity constraints for amount backordered of first period
...
nonantcb163 nonanticipativity constraints for amount backordered of first period
nonantcb21 nonanticipativity constraints for amount backordered of second period
...
nonantcb260 nonanticipativity constraints for amount backordered of second period
nonantcb31 nonanticipativity constraints for amount backordered of third period
...
nonantcb348 nonanticipativity constraints for amount backordered of third period;

cost2..  zSUB =e= sum(sc, prob(sc)*sum(t, invprice*invs1(t, sc) + backprice*backs1(t, sc)));
inves1(sc).. invs1('1', sc) - backs1('1', sc) =e= invens - backs + f0s('1', sc) - RealizedDemand;
```

```
inves2(sc).. invs1('2', sc) - backs1('2', sc) =e= invs1('1', sc) - backs1('1', sc)+f0s('2', sc)-dem('2', sc);
inves3(sc).. invs1('3', sc) - backs1('3', sc) =e= invs1('2', sc) - backs1('2', sc)+f0s('3', sc)-dem('3', sc);
inves4(sc).. invs1('4', sc) - backs1('4', sc) =e= invs1('3', sc) - backs1('3', sc)+f0s('4', sc)-dem('4', sc);

ucfs2(sc).. - f0s('2', sc) =g= - flexup('2')*f1.l('2');
dcfs2(sc).. f0s('2', sc) =g= flexdown('2')*f1.l('2');
ucfs3(sc).. - f0s('3', sc) =g= - flexup('3')*f1.l('3');
dcfs3(sc).. f0s('3', sc) =g= flexdown('3')*f1.l('3');
ucfs4(sc).. f0s('4', sc) =l= flexup('4')*f1s('4', sc);
dcfs4(sc).. f0s('4', sc) =g= flexdown('4')*f1s('4', sc);
uifs1(sc).. f0s('1', sc) =l= previousflexup('1');
difs1(sc).. f0s('1', sc) =g= previousflexdown('1');

nonantci11.. invs1('1', '1') =e= invs1('1', '2');
nonantci12.. invs1('1', '2') =e= invs1('1', '3');
nonantci13.. invs1('1', '3') =e= invs1('1', '4');
nonantci14.. invs1('1', '4') =e= invs1('1', '5');
nonantci15.. invs1('1', '5') =e= invs1('1', '6');
nonantci16.. invs1('1', '6') =e= invs1('1', '7');
nonantci17.. invs1('1', '7') =e= invs1('1', '8');
nonantci18.. invs1('1', '8') =e= invs1('1', '9');
nonantci19.. invs1('1', '9') =e= invs1('1', '10');
nonantci110.. invs1('1', '10')=e= invs1('1', '11');
nonantci111.. invs1('1', '11')=e= invs1('1', '12');
nonantci112.. invs1('1', '12')=e= invs1('1', '13');
nonantci113.. invs1('1', '13')=e= invs1('1', '14');
nonantci114.. invs1('1', '14')=e= invs1('1', '15');
nonantci115.. invs1('1', '15')=e= invs1('1', '16');
nonantci116.. invs1('1', '16')=e= invs1('1', '17');
nonantci117.. invs1('1', '17')=e= invs1('1', '18');
nonantci118.. invs1('1', '18')=e= invs1('1', '19');
nonantci119.. invs1('1', '19')=e= invs1('1', '20');
nonantci120.. invs1('1', '20')=e= invs1('1', '21');
nonantci121.. invs1('1', '21')=e= invs1('1', '22');
nonantci122.. invs1('1', '22')=e= invs1('1', '23');
nonantci123.. invs1('1', '23')=e= invs1('1', '24');
nonantci124.. invs1('1', '24')=e= invs1('1', '25');
nonantci125.. invs1('1', '25')=e= invs1('1', '26');
nonantci126.. invs1('1', '26')=e= invs1('1', '27');
nonantci127.. invs1('1', '27')=e= invs1('1', '28');
nonantci128.. invs1('1', '28')=e= invs1('1', '29');
nonantci129.. invs1('1', '29')=e= invs1('1', '30');
nonantci130.. invs1('1', '30')=e= invs1('1', '31');
nonantci131.. invs1('1', '31')=e= invs1('1', '32');
nonantci132.. invs1('1', '32')=e= invs1('1', '33');
nonantci133.. invs1('1', '33')=e= invs1('1', '34');
nonantci134.. invs1('1', '34')=e= invs1('1', '35');
nonantci135.. invs1('1', '35')=e= invs1('1', '36');
nonantci136.. invs1('1', '36')=e= invs1('1', '37');
nonantci137.. invs1('1', '37')=e= invs1('1', '38');
nonantci138.. invs1('1', '38')=e= invs1('1', '39');
nonantci139.. invs1('1', '39')=e= invs1('1', '40');
nonantci140.. invs1('1', '40')=e= invs1('1', '41');
nonantci141.. invs1('1', '41')=e= invs1('1', '42');
nonantci142.. invs1('1', '42')=e= invs1('1', '43');
nonantci143.. invs1('1', '43')=e= invs1('1', '44');
nonantci144.. invs1('1', '44')=e= invs1('1', '45');
nonantci145.. invs1('1', '45')=e= invs1('1', '46');
nonantci146.. invs1('1', '46')=e= invs1('1', '47');
nonantci147.. invs1('1', '47')=e= invs1('1', '48');
nonantci148.. invs1('1', '48')=e= invs1('1', '49');
nonantci149.. invs1('1', '49')=e= invs1('1', '50');
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nonantci150.. invs1('1', '50')=e= invs1('1', '51');
nonantci151.. invs1('1', '51')=e= invs1('1', '52');
nonantci152.. invs1('1', '52')=e= invs1('1', '53');
nonantci153.. invs1('1', '53')=e= invs1('1', '54');
nonantci154.. invs1('1', '54')=e= invs1('1', '55');
nonantci155.. invs1('1', '55')=e= invs1('1', '56');
nonantci156.. invs1('1', '56')=e= invs1('1', '57');
nonantci157.. invs1('1', '57')=e= invs1('1', '58');
nonantci158.. invs1('1', '58')=e= invs1('1', '59');
nonantci159.. invs1('1', '59')=e= invs1('1', '60');
nonantci160.. invs1('1', '60')=e= invs1('1', '61');
nonantci161.. invs1('1', '61')=e= invs1('1', '62');
nonantci162.. invs1('1', '62')=e= invs1('1', '63');
nonantci163.. invs1('1', '63')=e= invs1('1', '64');
nonantci21.. invs1('2', '1') =e= invs1('2', '2');
nonantci22.. invs1('2', '2') =e= invs1('2', '3');
nonantci23.. invs1('2', '3') =e= invs1('2', '4');
nonantci24.. invs1('2', '4') =e= invs1('2', '5');
nonantci25.. invs1('2', '5') =e= invs1('2', '6');
nonantci26.. invs1('2', '6') =e= invs1('2', '7');
nonantci27.. invs1('2', '7') =e= invs1('2', '8');
nonantci28.. invs1('2', '8') =e= invs1('2', '9');
nonantci29.. invs1('2', '9') =e= invs1('2', '10');
nonantci210.. invs1('2', '10')=e= invs1('2', '11');
nonantci211.. invs1('2', '11')=e= invs1('2', '12');
nonantci212.. invs1('2', '12')=e= invs1('2', '13');
nonantci213.. invs1('2', '13')=e= invs1('2', '14');
nonantci214.. invs1('2', '14')=e= invs1('2', '15');
nonantci215.. invs1('2', '15')=e= invs1('2', '16');
nonantci216.. invs1('2', '17')=e= invs1('2', '18');
nonantci217.. invs1('2', '18')=e= invs1('2', '19');
nonantci218.. invs1('2', '19')=e= invs1('2', '20');
nonantci219.. invs1('2', '20')=e= invs1('2', '21');
nonantci220.. invs1('2', '21')=e= invs1('2', '22');
nonantci221.. invs1('2', '22')=e= invs1('2', '23');
nonantci222.. invs1('2', '23')=e= invs1('2', '24');
nonantci223.. invs1('2', '24')=e= invs1('2', '25');
nonantci224.. invs1('2', '25')=e= invs1('2', '26');
nonantci225.. invs1('2', '26')=e= invs1('2', '27');
nonantci226.. invs1('2', '27')=e= invs1('2', '28');
nonantci227.. invs1('2', '28')=e= invs1('2', '29');
nonantci228.. invs1('2', '29')=e= invs1('2', '30');
nonantci229.. invs1('2', '30')=e= invs1('2', '31');
nonantci230.. invs1('2', '31')=e= invs1('2', '32');
nonantci231.. invs1('2', '33')=e= invs1('2', '34');
nonantci232.. invs1('2', '34')=e= invs1('2', '35');
nonantci233.. invs1('2', '35')=e= invs1('2', '36');
nonantci234.. invs1('2', '36')=e= invs1('2', '37');
nonantci235.. invs1('2', '37')=e= invs1('2', '38');
nonantci236.. invs1('2', '38')=e= invs1('2', '39');
nonantci237.. invs1('2', '39')=e= invs1('2', '40');
nonantci238.. invs1('2', '40')=e= invs1('2', '41');
nonantci239.. invs1('2', '41')=e= invs1('2', '42');
nonantci240.. invs1('2', '42')=e= invs1('2', '43');
nonantci241.. invs1('2', '43')=e= invs1('2', '44');
nonantci242.. invs1('2', '44')=e= invs1('2', '45');
nonantci243.. invs1('2', '45')=e= invs1('2', '46');
nonantci244.. invs1('2', '46')=e= invs1('2', '47');
nonantci245.. invs1('2', '47')=e= invs1('2', '48');
nonantci246.. invs1('2', '49')=e= invs1('2', '50');
nonantci247.. invs1('2', '50')=e= invs1('2', '51');
nonantci248.. invs1('2', '51')=e= invs1('2', '52');
nonantci249.. invs1('2', '52')=e= invs1('2', '53');
nonantci250.. invs1('2', '53')=e= invs1('2', '54');
nonantci251.. invs1('2', '54')=e= invs1('2', '55');
nonantci252.. invs1('2', '55')=e= invs1('2', '56');
nonantci253.. invs1('2', '56')=e= invs1('2', '57');
nonantci254.. invs1('2', '57')=e= invs1('2', '58');
nonantci255.. invs1('2', '58')=e= invs1('2', '59');
nonantci256.. invs1('2', '59')=e= invs1('2', '60');
nonantci257.. invs1('2', '60')=e= invs1('2', '61');
nonantci258.. invs1('2', '61')=e= invs1('2', '62');
nonantci259.. invs1('2', '62')=e= invs1('2', '63');
nonantci260.. invs1('2', '63')=e= invs1('2', '64');
nonantci31.. invs1('3', '1') =e= invs1('3', '2');
nonantci32.. invs1('3', '2') =e= invs1('3', '3');
nonantci33.. invs1('3', '3') =e= invs1('3', '4');
nonantci34.. invs1('3', '5') =e= invs1('3', '6');
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nonantci35.. invs1('3', '6') =e= invs1('3', '7');
nonantci36.. invs1('3', '7') =e= invs1('3', '8');
nonantci37.. invs1('3', '9') =e= invs1('3', '10');
nonantci38.. invs1('3', '10') =e= invs1('3', '11');
nonantci39.. invs1('3', '11') =e= invs1('3', '12');
nonantci310.. invs1('3', '13')=e= invs1('3', '14');
nonantci311.. invs1('3', '14')=e= invs1('3', '15');
nonantci312.. invs1('3', '15')=e= invs1('3', '16');
nonantci313.. invs1('3', '17')=e= invs1('3', '18');
nonantci314.. invs1('3', '18')=e= invs1('3', '19');
nonantci315.. invs1('3', '19')=e= invs1('3', '20');
nonantci316.. invs1('3', '21')=e= invs1('3', '22');
nonantci317.. invs1('3', '22')=e= invs1('3', '23');
nonantci318.. invs1('3', '23')=e= invs1('3', '24');
nonantci319.. invs1('3', '25')=e= invs1('3', '26');
nonantci320.. invs1('3', '26')=e= invs1('3', '27');
nonantci321.. invs1('3', '27')=e= invs1('3', '28');
nonantci322.. invs1('3', '29')=e= invs1('3', '30');
nonantci323.. invs1('3', '30')=e= invs1('3', '31');
nonantci324.. invs1('3', '31')=e= invs1('3', '32');
nonantci325.. invs1('3', '33')=e= invs1('3', '34');
nonantci326.. invs1('3', '34')=e= invs1('3', '35');
nonantci327.. invs1('3', '35')=e= invs1('3', '36');
nonantci328.. invs1('3', '37')=e= invs1('3', '38');
nonantci329.. invs1('3', '38')=e= invs1('3', '39');
nonantci330.. invs1('3', '39')=e= invs1('3', '40');
nonantci331.. invs1('3', '41')=e= invs1('3', '42');
nonantci332.. invs1('3', '42')=e= invs1('3', '43');
nonantci333.. invs1('3', '43')=e= invs1('3', '44');
nonantci334.. invs1('3', '45')=e= invs1('3', '46');
nonantci335.. invs1('3', '46')=e= invs1('3', '47');
nonantci336.. invs1('3', '47')=e= invs1('3', '48');
nonantci337.. invs1('3', '49')=e= invs1('3', '50');
nonantci338.. invs1('3', '50')=e= invs1('3', '51');
nonantci339.. invs1('3', '51')=e= invs1('3', '52');
nonantci340.. invs1('3', '53')=e= invs1('3', '54');
nonantci341.. invs1('3', '54')=e= invs1('3', '55');
nonantci342.. invs1('3', '55')=e= invs1('3', '56');
nonantci343.. invs1('3', '57')=e= invs1('3', '58');
nonantci344.. invs1('3', '58')=e= invs1('3', '59');
nonantci345.. invs1('3', '59')=e= invs1('3', '60');
nonantci346.. invs1('3', '61')=e= invs1('3', '62');
nonantci347.. invs1('3', '62')=e= invs1('3', '63');
nonantci348.. invs1('3', '63')=e= invs1('3', '64');
nonantcb11.. backs1('1', '1') =e= backs1('1', '2');
nonantcb12.. backs1('1', '2') =e= backs1('1', '3');
nonantcb13.. backs1('1', '3') =e= backs1('1', '4');
nonantcb14.. backs1('1', '4') =e= backs1('1', '5');
nonantcb15.. backs1('1', '5') =e= backs1('1', '6');
nonantcb16.. backs1('1', '6') =e= backs1('1', '7');
nonantcb17.. backs1('1', '7') =e= backs1('1', '8');
nonantcb18.. backs1('1', '8') =e= backs1('1', '9');
nonantcb19.. backs1('1', '9')=e= backs1('1', '10');
nonantcb110.. backs1('1', '10')=e=backs1('1','11');
nonantcb111.. backs1('1', '11')=e=backs1('1','12');
nonantcb112.. backs1('1', '12')=e=backs1('1','13');
nonantcb113.. backs1('1', '13')=e=backs1('1','14');
nonantcb114.. backs1('1', '14')=e=backs1('1','15');
nonantcb115.. backs1('1', '15')=e=backs1('1','16');
nonantcb116.. backs1('1', '16')=e=backs1('1','17');
nonantcb117.. backs1('1', '17')=e=backs1('1','18');
nonantcb118.. backs1('1', '18')=e=backs1('1','19');
nonantcb119.. backs1('1', '19')=e=backs1('1','20');
nonantcb120.. backs1('1', '20')=e=backs1('1','21');
nonantcb121.. backs1('1', '21')=e=backs1('1','22');
nonantcb122.. backs1('1', '22')=e=backs1('1','23');
nonantcb123.. backs1('1', '23')=e=backs1('1','24');
nonantcb124.. backs1('1', '24')=e=backs1('1','25');
nonantcb125.. backs1('1', '25')=e=backs1('1','26');
nonantcb126.. backs1('1', '26')=e=backs1('1','27');
nonantcb127.. backs1('1', '27')=e=backs1('1','28');
nonantcb128.. backs1('1', '28')=e=backs1('1','29');
nonantcb129.. backs1('1', '29')=e=backs1('1','30');
nonantcb130.. backs1('1', '30')=e=backs1('1','31');
nonantcb131.. backs1('1', '31')=e=backs1('1','32');
nonantcb132.. backs1('1', '32')=e=backs1('1','33');
nonantcb133.. backs1('1', '33')=e=backs1('1','34');
nonantcb134.. backs1('1', '34')=e=backs1('1','35');
```

```
nonantcb135.. backs1('1', '35')=e=backs1('1','36');
nonantcb136.. backs1('1', '36')=e=backs1('1','37');
nonantcb137.. backs1('1', '37')=e=backs1('1','38');
nonantcb138.. backs1('1', '38')=e=backs1('1','39');
nonantcb139.. backs1('1', '39')=e=backs1('1','40');
nonantcb140.. backs1('1', '40')=e=backs1('1','41');
nonantcb141.. backs1('1', '41')=e=backs1('1','42');
nonantcb142.. backs1('1', '42')=e=backs1('1','43');
nonantcb143.. backs1('1', '43')=e=backs1('1','44');
nonantcb144.. backs1('1', '44')=e=backs1('1','45');
nonantcb145.. backs1('1', '45')=e=backs1('1','46');
nonantcb146.. backs1('1', '46')=e=backs1('1','47');
nonantcb147.. backs1('1', '47')=e=backs1('1','48');
nonantcb148.. backs1('1', '48')=e=backs1('1','49');
nonantcb149.. backs1('1', '49')=e=backs1('1','50');
nonantcb150.. backs1('1', '50')=e=backs1('1','51');
nonantcb151.. backs1('1', '51')=e=backs1('1','52');
nonantcb152.. backs1('1', '52')=e=backs1('1','53');
nonantcb153.. backs1('1', '53')=e=backs1('1','54');
nonantcb154.. backs1('1', '54')=e=backs1('1','55');
nonantcb155.. backs1('1', '55')=e=backs1('1','56');
nonantcb156.. backs1('1', '56')=e=backs1('1','57');
nonantcb157.. backs1('1', '57')=e=backs1('1','58');
nonantcb158.. backs1('1', '58')=e=backs1('1','59');
nonantcb159.. backs1('1', '59')=e=backs1('1','60');
nonantcb160.. backs1('1', '60')=e=backs1('1','61');
nonantcb161.. backs1('1', '61')=e=backs1('1','62');
nonantcb162.. backs1('1', '62')=e=backs1('1','63');
nonantcb163.. backs1('1', '63')=e=backs1('1','64');
nonantcb21.. backs1('2', '1') =e= backs1('2', '2');
nonantcb22.. backs1('2', '2') =e= backs1('2', '3');
nonantcb23.. backs1('2', '3') =e= backs1('2', '4');
nonantcb24.. backs1('2', '4') =e= backs1('2', '5');
nonantcb25.. backs1('2', '5') =e= backs1('2', '6');
nonantcb26.. backs1('2', '6') =e= backs1('2', '7');
nonantcb27.. backs1('2', '7') =e= backs1('2', '8');
nonantcb28.. backs1('2', '8') =e= backs1('2', '9');
nonantcb29.. backs1('2', '9') =e= backs1('2','10');
nonantcb210.. backs1('2', '10')=e= backs1('2',11');
```

```
nonantcb211.. backs1('2', '11')=e=backs1('2','12');
nonantcb212.. backs1('2', '12')=e=backs1('2','13');
nonantcb213.. backs1('2', '13')=e=backs1('2','14');
nonantcb214.. backs1('2', '14')=e=backs1('2','15');
nonantcb215.. backs1('2', '15')=e=backs1('2','16');
nonantcb216.. backs1('2', '17')=e=backs1('2','18');
nonantcb217.. backs1('2', '18')=e=backs1('2','19');
nonantcb218.. backs1('2', '19')=e=backs1('2','20');
nonantcb219.. backs1('2', '20')=e=backs1('2','21');
nonantcb220.. backs1('2', '21')=e=backs1('2','22');
nonantcb221.. backs1('2', '22')=e=backs1('2','23');
nonantcb222.. backs1('2', '23')=e=backs1('2','24');
nonantcb223.. backs1('2', '24')=e=backs1('2','25');
nonantcb224.. backs1('2', '25')=e=backs1('2','26');
nonantcb225.. backs1('2', '26')=e=backs1('2','27');
nonantcb226.. backs1('2', '27')=e=backs1('2','28');
nonantcb227.. backs1('2', '28')=e=backs1('2','29');
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nonantcb257.. backs1('2', '60')=e=backs1('2','61');
nonantcb258.. backs1('2', '61')=e=backs1('2','62');
nonantcb259.. backs1('2', '62')=e=backs1('2','63');
nonantcb260.. backs1('2', '63')=e=backs1('2','64');
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nonantcb32.. backs1('3', '2') =e= backs1('3', '3');
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nonantcb344.. backs1('3', '58')=e=backs1('3','59');
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nonantcb346.. backs1('3', '61')=e=backs1('3','62');
nonantcb347.. backs1('3', '62')=e=backs1('3','63');
nonantcb348.. backs1('3', '63')=e=backs1('3','64');

model sub /cost2, inves1, inves2, inves3, inves4, ucfs2,
dcfs2, ucfs3, dcfs3, ucfs4, dcfs4, uifs1, difs1,
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nonantcb338, nonantcb339, nonantcb340,
nonantcb341, nonantcb342, nonantcb343, nonantcb344,
nonantcb345, nonantcb346, nonantcb347, nonantcb348 /;
```

```
set ss / 1*20/
    s(ss);
parameter rep(ss, *)
pinvs1(t, sc, ss)
pbacks1(t, sc, ss)
dualucfs2(sc, ss)
dualdcfs2(sc, ss)
dualucfs3(sc, ss)
dualdcfs3(sc, ss)
lastff0(*, sc)
ff0(*, sc, ss);
equations
cost3 define objective function of Master Problem
uifmaster2 upward incremental flexibility of the second period
difmaster2 downward incremental flexibility of the second period
uifmaster3 upward incremental flexibility of the third period
difmaster3 downward incremental flexibility of the third period
benderscuts(ss)  Bender's CUT
fc1(sc) Feasibility constraints
fc2(sc) Feasibility constraints
fc3(sc) Feasibility constraints
fc4(sc) Feasibility constraints;
cost3..  zMASTER =e= M;
uifmaster2.. f1('2') =l= previousflexup('2');
difmaster2.. f1('2') =g= previousflexdown('2');
uifmaster3.. f1('3') =l= previousflexup('3');
difmaster3.. f1('3') =g= previousflexdown('3');
fc1(sc).. lastff0('2', sc) =l= flexup('2')*f1('2');
fc2(sc).. lastff0('2', sc) =g= flexdown('2')*f1('2');
```

```
fc3(sc).. lastff0('3', sc) =l= flexup('3')*f1('3');
fc4(sc).. lastff0('3', sc) =g= flexdown('3')*f1('3');
benderscuts(s).. M =g=  sum(sc, prob(sc)*(sum(t, invprice*pinvs1(t, sc, s) + backprice*pbacks1(t, sc, s)))) +
sum(sc, dualucfs2(sc, s)*( - flexup('2')*f1('2') + ff0('2',sc, s))) +
sum(sc, dualdcfs2(sc, s)*(flexdown('2')*f1('2') - ff0('2', sc, s))) +
sum(sc, dualucfs3(sc, s)*(- flexup('3')*f1('3') + ff0('3',sc, s))) +
sum(sc, dualdcfs3(sc, s)*(flexdown('3')*f1('3') - ff0('3', sc, s)));

model master /cost3, uifmaster2, difmaster2, uifmaster3, difmaster3, fc1, fc2, fc3, fc4, benderscuts/;
rep('1', 'gap') = inf;
rep('1', 'lb') = -inf;
rep('1', 'ub') = inf;

loop (ss$(rep(ss, 'gap') > 0.01 ),

         solve sub using lp minimizing zSUB;
         rep(ss + 1, 'subopt') = zSUB.l;
         rep(ss + 1, 'ub') = min(rep(ss, 'ub'), rep(ss + 1, 'subopt'));
         s(ss) = ord(ss);
         pinvs1(t, sc, ss) = invs1.l(t, sc);
         pbacks1(t, sc, ss) = backs1.l(t, sc);
         dualucfs2(sc, ss) = ucfs2.m(sc);
         dualdcfs2(sc, ss) = dcfs2.m(sc);
         dualucfs3(sc, ss) = ucfs3.m(sc);
         dualdcfs3(sc, ss) = dcfs3.m(sc);
         ff0('2', sc, ss) = f0s.l('2', sc);
         ff0('3', sc, ss) = f0s.l('3', sc);
         lastff0('2', sc ) = f0s.l('2', sc);
         lastff0('3', sc ) = f0s.l('3', sc);

         solve master using lp minimizing zMASTER;
         rep(ss + 1, 'mastopt') = zMASTER.l;
         rep(ss + 1, 'lb') = rep(ss + 1, 'mastopt');
         rep(ss + 1, 'gap') = rep(ss + 1, 'ub') - rep(ss + 1, 'lb'); );
display M.l, inv1.l, back1.l, invs1.l, backs1.l, f0s.l, f1.l, p, rep;
```

APPENDIX E

AVERAGE COSTS OF THE SUPPLY CHAIN ACTORS IN DECENTRALIZED ENVIRONMENT IN THE SECOND CASE

Table E.1 Average Costs of the SC Actors in the Decentralized Environment in Medium DEVAR

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

		DECENTRALIZED ENVIRONMENT			
DEVAR	**(F_{B2}, F_M) / (C_B, C_M)**	1st Buyer	2nd Buyer	Manufacturer	Total
MEDIUM DEVAR	(T.T) / (L.L)	0.0	213.9	2442.9	2656.8
	(T.T) / (L.H)	0.0	213.9	4556.5	4770.4
	(T.T) / (H.L)	0.2	305.6	2479.4	2785.2
	(T.T) / (H.H)	0.2	305.6	4629.8	4935.6
	(T.L) / (L.L)	0.0	213.9	2441.0	2654.9
	(T.L) / (L.H)	0.0	213.9	4553.5	4767.4
	(T.L) / (H.L)	0.2	305.6	2477.5	2783.3
	(T.L) / (H.H)	0.2	305.6	4626.8	4932.6
	(L.T) / (L.L)	0.0	92.8	2386.5	2479.3
	(L.T) / (L.H)	0.0	92.8	4397.1	4489.9
	(L.T) / (H.L)	0.2	92.8	2408.9	2501.9
	(L.T) / (H.H)	0.2	92.8	4437.8	4530.8
	(L.L) / (L.L)	0.0	92.8	2384.8	2477.6
	(L.L) / (L.H)	0.0	92.8	4394.5	4487.3
	(L.L) / (H.L)	0.2	92.8	2407.3	2500.3
	(L.L) / (H.H)	0.2	92.8	4435.2	4528.2

Table E.2 Average Costs of the SC Actors in the Decentralized Environment in High DEVAR

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

		DECENTRALIZED ENVIRONMENT			
DEVAR	**(F_{B2}. F_M) / (C_B. C_M)**	1st Buyer	2nd Buyer	Manufacturer	Total
HIGH DEVAR	(T.T) / (L.L)	130.6	164.7	3172.0	3467.3
	(T.T) / (L.H)	130.6	164.7	5790.4	6085.7
	(T.T) / (H.L)	130.9	265.6	3294.8	3691.2
	(T.T) / (H.H)	130.9	265.6	6013.4	6409.9
	(T.L) / (L.L)	130.6	164.7	3169.5	3464.8
	(T.L) / (L.H)	130.6	164.7	5787.4	6082.7
	(T.L) / (H.L)	130.9	265.6	3292.3	3688.8
	(T.L) / (H.H)	130.9	265.6	6010.3	6406.7
	(L.T) / (L.L)	130.6	100.1	3157.8	3388.4
	(L.T) / (L.H)	130.6	100.1	5745.0	5975.7
	(L.T) / (H.L)	130.9	96.4	3192.0	3419.3
	(L.T) / (H.H)	130.9	96.4	5806.0	6033.2
	(L.L) / (L.L)	130.6	100.1	3155.5	3386.2
	(L.L) / (L.H)	130.6	100.1	5742.1	5972.7
	(L.L) / (H.L)	130.9	96.4	3189.9	3417.1
	(L.L) / (H.H)	130.9	96.4	5803.0	6030.3

APPENDIX F

AVERAGE COSTS OF THE SUPPLY CHAIN ACTORS IN CENTRALIZED ENVIRONMENT IN THE SECOND CASE

Table F.1 Average Costs of the SC Actors in the Centralized Environment in Medium DEVAR

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

		CENTRALIZED ENVIRONMENT			
DEVAR	**$(F_{B2}. F_M) / (C_B. C_M)$**	1st Buyer	2nd Buyer	Manufacturer	Total
MEDIUM DEVAR	(T.T) / (L.L)	187.0	212.1	1986.5	2385.5
	(T.T) / (L.H)	255.0	638.6	2016.4	2910.1
	(T.T) / (H.L)	213.1	330.3	2047.2	2590.7
	(T.T) / (H.H)	213.3	334.5	4054.2	4601.9
	(T.L) / (L.L)	180.9	212.1	1998.9	2391.8
	(T.L) / (L.H)	256.7	638.6	2016.7	2912.0
	(T.L) / (H.L)	184.6	330.3	2075.7	2590.7
	(T.L) / (H.H)	213.3	335.4	4068.1	4616.7
	(L.T) / (L.L)	144.6	121.2	1970.8	2236.6
	(L.T) / (L.H)	174.5	582.6	2192.7	2949.9
	(L.T) / (H.L)	195.7	132.5	2009.4	2337.6
	(L.T) / (H.H)	175.4	117.5	3971.2	4264.1
	(L.L) / (L.L)	206.3	119.0	1914.5	2239.8
	(L.L) / (L.H)	200.6	567.2	2184.2	2951.9
	(L.L) / (H.L)	210.9	122.7	1993.9	2327.5
	(L.L) / (H.H)	205.4	105.2	3953.3	4263.9

Table F.2 Average Costs of the SC Actors in the Centralized Environment in High DEVAR

DEVAR: Medium/High ; FLEX: Tight/Loose ; COST: Low/High

		CENTRALIZED ENVIRONMENT			
DEVAR	**(F_{B2}. F_M) / (C_B. C_M)**	1st Buyer	2nd Buyer	Manufacturer	Total
HIGH DEVAR	(T.T) / (L.L)	241.4	261.7	2437.3	2940.4
	(T.T) / (L.H)	441.0	1070.6	2409.9	3921.4
	(T.T) / (H.L)	265.7	377.2	2602.2	3245.2
	(T.T) / (H.H)	298.8	316.7	4812.5	5427.9
	(T.L) / (L.L)	228.4	262.5	2444.3	2935.2
	(T.L) / (L.H)	355.9	1077.1	2434.6	3867.6
	(T.L) / (H.L)	294.2	458.5	2619.9	3372.7
	(T.L) / (H.H)	296.9	317.9	4815.0	5429.7
	(L.T) / (L.L)	246.4	241.3	2419.8	2907.5
	(L.T) / (L.H)	509.2	912.4	2468.2	3889.9
	(L.T) / (H.L)	278.2	216.7	2644.7	3139.6
	(L.T) / (H.H)	333.5	201.8	4887.7	5422.9
	(L.L) / (L.L)	242.0	233.6	2439.8	2915.4
	(L.L) / (L.H)	321.7	1079.0	2458.7	3859.3
	(L.L) / (H.L)	250.4	217.9	2660.2	3128.5
	(L.L) / (H.H)	296.8	218.7	4861.6	5377.1

APPENDIX G

SINGLE FACTOR MODEL RESULTS OF THE FIRST CASE

Table G.1 Tukey's Tests Results for the SC Actors in the Decentralized Environment

DM Case	Environment	SC Actor	**TUKEY'S TEST** $[(F_{B1},F_M)/(C_B,C_M)]$ Medium DEVAR	High DEVAR
2^{ND} BUYER FOR HERSELF	DECENTRALIZED	FIRST BUYER	| [(T,*)/(H,*)] | [(T,*)/(L,*)] | [(L,*)/(H,*)] | [(L,*)/(L,*)]	| [(T,*)/(H,*)] | [(T,*)/(L,*)] | [(T,*)/(L,*)] | [(L,*)/(H,*)] | [(L,*)/(L,*)]
		SECOND BUYER	| [(*,*)/(H,*)] | [(*,*)/(L,*)]	| [(*,*)/(H,*)] | [(*,*)/(L,*)]

TUKEY'S TEST
$[(F_{B1},F_M)/(C_B,C_M)]$

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
2^{ND} BUYER FOR HERSELF	DECENTRALIZED	MANUFACTURER	[(T,T)/(H,H)]		[(T,T)/(H,H)]	
			[(T,T)/(L,H)]		[(T,L)/(H,H)]	
			[(T,L)/(H,H)]		[(T,T)/(L,H)]	
			[(T,L)/(L,H)]		[(T,L)/(L,H)]	
			[(L,T)/(H,H)]		[(L,T)/(H,H)]	
			[(L,T)/(L,H)]		[(L,T)/(L,H)]	
			[(L,L)/(H,H)]		[(L,L)/(H,H)]	
			[(L,L)/(L,H)]		[(L,L)/(L,H)]	
				[(T,T)/(H,L)]		[(T,T)/(H,L)]
				[(T,T)/(L,L)]		[(T,L)/(H,L)]
				[(T,L)/(H,L)]		[(T,T)/(L,L)]
				[(T,L)/(L,L)]		[(T,L)/(L,L)]
				[(L,T)/(H,L)]		[(L,T)/(H,L)]
				[(L,T)/(L,L)]		[(L,T)/(L,L)]
				[(L,L)/(H,L)]		[(L,L)/(H,L)]
				[(L,L)/(L,L)]		[(L,L)/(L,L)]

Table G.2 Different Results of Duncan’s Tests for the SC Actors in the Decentralized Environment

DM Case	Environment	SC Actor	**DUNCAN'S TEST** $[(F_{B1},F_M)/(C_B,C_M)]$ Medium DEVAR	High DEVAR
2ND BUYER FOR HERSELF	DECENTRALIZED	FIRST BUYER		[(T,*)/(H,*)] [(T,*)/(L,*)] ; [(T,*)/(L,*)] [(L,*)/(H,*)] [(L,*)/(L,*)]
		SECOND BUYER	[(*,*)/(H,*)] [(*,*)/(L,*)]	[(*,*)/(H,*)] [(*,*)/(L,*)]
		MANUFACTURER	[(T,T)/(H,H)] [(T,T)/(L,H)] [(T,L)/(H,H)] [(T,L)/(L,H)] [(L,T)/(H,H)] [(L,T)/(L,H)] [(L,L)/(H,H)] [(L,L)/(L,H)] [(T,T)/(H,L)] [(T,T)/(L,L)] [(T,L)/(H,L)] [(T,L)/(L,L)] [(L,T)/(H,L)] [(L,T)/(L,L)] [(L,L)/(H,L)] [(L,L)/(L,L)]	

Table G.3 Tukey’s Tests Results for the First Buyer in the Centralized Environment

TUKEY'S TEST
$[(F_{B1},F_M)/(C_B,C_M)]$

DM Case	Environment	SC Actor	Medium DEVAR			High DEVAR		
2ND BUYER DETERMINES FOR HERSELF	CENTRALIZED	FIRST BUYER	[(L,L)/(L,H)]			[(L,T)/(L,H)]		
			[(L,T)/(L,H)]	[(L,T)/(L,H)]		[(T,T)/(L,H)]	[(T,T)/(L,H)]	
			[(T,T)/(L,H)]	[(T,T)/(L,H)]	[(T,T)/(L,H)]	[(T,L)/(L,H)]	[(T,L)/(L,H)]	
				[(T,L)/(L,H)]	[(T,L)/(L,H)]	[(L,L)/(L,H)]	[(L,L)/(L,H)]	
					[(L,T)/(H,L)]	[(T,L)/(H,H)]	[(T,L)/(H,H)]	
					[(L,T)/(H,H)]	[(T,T)/(H,H)]	[(T,T)/(H,H)]	
					[(L,T)/(L,L)]	[(T,T)/(H,L)]	[(T,T)/(H,L)]	
					[(L,L)/(H,H)]		[(T,L)/(H,L)]	[(T,L)/(H,L)]
					[(T,T)/(H,L)]			[(T,T)/(L,L)]
					[(T,L)/(H,H)]			[(T,L)/(L,L)]
					[(L,L)/(L,L)]			[(L,T)/(H,H)]
					[(L,L)/(H,L)]			[(L,L)/(H,H)]
					[(T,L)/(H,L)]			[(L,T)/(H,L)]
					[(T,T)/(H,H)]			[(L,L)/(H,L)]
					[(T,T)/(L,L)]			[(L,T)/(L,L)]
					[(T,L)/(L,L)]			[(L,L)/(L,L)]

Table G.4 Tukey's Tests Results for the Second Buyer in the Centralized Environment

DM Case	Environment	SC Actor	**TUKEY'S TEST** [$(F_{B1},F_M)/(C_B,C_M)$] Medium DEVAR			High DEVAR	
2^{ND} BUYER DETERMINES FOR HERSELF	CENTRALIZED	SECOND BUYER	[(L,L)/(L,H)]			[(T,T)/(L,H)]	
			[(L,T)/(L,H)]	[(L,T)/(L,H)]		[(T,L)/(L,H)]	
			[(T,L)/(L,H)]	[(T,L)/(L,H)]		[(L,T)/(L,H)]	
			[(T,T)/(L,H)]	[(T,T)/(L,H)]		[(L,L)/(L,H)]	
			[(T,T)/(H,H)]	[(T,T)/(H,H)]			[(L,T)/(H,L)]
			[(L,L)/(H,H)]	[(L,L)/(H,H)]			[(L,T)/(H,H)]
			[(T,L)/(H,H)]	[(T,L)/(H,H)]			[(L,L)/(H,H)]
			[(T,L)/(L,L)]	[(T,L)/(L,L)]			[(T,T)/(H,H)]
			[(L,T)/(H,H)]	[(L,T)/(H,H)]			[(T,T)/(H,L)]
			[(L,L)/(L,L)]	[(L,L)/(L,L)]			[(L,L)/(H,L)]
				[(T,T)/(H,L)]	[(T,T)/(H,L)]		[(T,L)/(H,H)]
				[(L,T)/(H,L)]	[(L,T)/(H,L)]		[(T,L)/(H,L)]
				[(L,T)/(L,L)]	[(L,T)/(L,L)]		[(L,T)/(L,L)]
				[(L,L)/(H,L)]	[(L,L)/(H,L)]		[(T,T)/(L,L)]
				[(T,T)/(L,L)]	[(T,T)/(L,L)]		[(L,L)/(L,L)]
					[(T,L)/(H,L)]		[(T,L)/(L,L)]

Table G.5 Tukey's Tests Results for the Manufacturer in the Centralized Environment

TUKEY'S TEST
[(F_{B1},F_M)/(C_B,C_M)]

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
2[ND] BUYER DETERMINES FOR HERSELF	CENTRALIZED	MANUFACTURER	[(T,T)/(H,H)]		[(T,L)/(H,H)]	
			[(T,L)/(H,H)]		[(T,T)/(H,H)]	
			[(L,T)/(H,H)]		[(L,L)/(H,H)]	
			[(L,L)/(H,H)]		[(L,T)/(H,H)]	
				[(T,L)/(L,H)]		[(L,L)/(H,L)]
				[(T,T)/(L,H)]		[(T,L)/(H,L)]
				[(L,L)/(L,H)]		[(T,T)/(H,L)]
				[(L,T)/(L,H)]		[(L,T)/(H,L)]
				[(T,L)/(H,L)]		[(T,L)/(L,H)]
				[(L,L)/(H,L)]		[(T,T)/(L,H)]
				[(T,T)/(H,L)]		[(T,L)/(L,L)]
				[(L,T)/(H,L)]		[(L,L)/(L,L)]
				[(T,L)/(L,L)]		[(T,T)/(L,L)]
				[(L,L)/(L,L)]		[(L,L)/(L,H)]
				[(T,T)/(L,L)]		[(L,T)/(L,H)]
				[(L,T)/(L,L)]		[(L,T)/(L,L)]

Table G.6 Different Results of Duncan's Tests for the First Buyer in the Centralized Environment

DUNCAN'S TEST
[$(F_{B1},F_M)/(C_B,C_M)$]

DM Case	Environment	SC Actor	Medium DEVAR					High DEVAR			
2^{ND} BUYER DETERMINES FOR HERSELF	CENTRALIZED	FIRST BUYER	[(L,L)/(L,H)]					[(L,T)/(L,H)]			
			[(L,T)/(L,H)]	[(L,T)/(L,H)]				[(T,T)/(L,H)]			
				[(T,T)/(L,H)]	[(T,T)/(L,H)]			[(T,L)/(L,H)]			
					[(T,L)/(L,H)]	[(T,L)/(L,H)]		[(L,L)/(L,H)]			
						[(L,T)/(H,L)]	[(L,T)/(H,L)]		[(T,L)/(H,H)]		
						[(L,T)/(H,H)]	[(L,T)/(H,H)]		[(T,T)/(H,H)]		
						[(L,T)/(L,L)]	[(L,T)/(L,L)]		[(T,T)/(H,L)]	[(T,T)/(H,L)]	
						[(L,L)/(H,H)]	[(L,L)/(H,H)]		[(T,L)/(H,L)]	[(T,L)/(H,L)]	[(T,L)/(H,L)]
						[(T,T)/(H,L)]	[(T,T)/(H,L)]		[(T,T)/(L,L)]	[(T,T)/(L,L)]	[(T,T)/(L,L)]
						[(T,L)/(H,H)]	[(T,L)/(H,H)]		[(T,L)/(L,L)]	[(T,L)/(L,L)]	[(T,L)/(L,L)]
							[(L,L)/(L,L)]			[(L,T)/(H,H)]	[(L,T)/(H,H)]
							[(L,L)/(H,L)]			[(L,L)/(H,H)]	[(L,L)/(H,H)]
							[(T,L)/(H,L)]			[(L,T)/(H,L)]	[(L,T)/(H,L)]
							[(T,T)/(H,H)]			[(L,L)/(H,L)]	[(L,L)/(H,L)]
							[(T,T)/(L,L)]			[(L,T)/(L,L)]	[(L,T)/(L,L)]
							[(T,L)/(L,L)]				[(L,L)/(L,L)]

Table G.7 Different Results of Duncan's Tests for the Second Buyer in the Centralized Environment

DUNCAN'S TEST

$[(F_{B1},F_M)/(C_B,C_M)]$

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR		
2ND BUYER DETERMINES FOR HERSELF	CENTRALIZED	SECOND BUYER	[(L,L)/(L,H)]		[(T,T)/(L,H)]		
			[(L,T)/(L,H)]		[(T,L)/(L,H)]		
			[(T,L)/(L,H)]			[(L,T)/(L,H)]	
			[(T,T)/(L,H)]			[(L,L)/(L,H)]	
				[(T,T)/(H,H)]			[(L,T)/(H,L)]
				[(L,L)/(H,H)]			[(L,T)/(H,H)]
				[(T,L)/(H,H)]			[(L,L)/(H,H)]
				[(T,L)/(L,L)]			[(T,T)/(H,H)]
				[(L,T)/(H,H)]			[(T,T)/(H,L)]
				[(L,L)/(L,L)]			[(L,L)/(H,L)]
				[(T,T)/(H,L)]			[(T,L)/(H,H)]
				[(L,T)/(H,L)]			[(T,L)/(H,L)]
				[(L,T)/(L,L)]			[(L,T)/(L,L)]
				[(L,L)/(H,L)]			[(T,T)/(L,L)]
				[(T,T)/(L,L)]			[(L,L)/(L,L)]
				[(T,L)/(H,L)]			[(T,L)/(L,L)]

Table G.8 Different Results of Duncan's Tests for the Manufacturer in the Centralized Environment

DUNCAN'S TEST

[(F_{B1},F_M)/(C_B,C_M)]

DM Case	Environment	SC Actor	Medium DEVAR			
2ND BUYER DETERMINES FOR HERSELF	CENTRALIZED	MANUFACTURER	[(T,T)/(H,H)]			
			[(T,L)/(H,H)]			
			[(L,T)/(H,H)]			
			[(L,L)/(H,H)]			
				[(T,L)/(L,H)]		
				[(T,T)/(L,H)]		
				[(L,L)/(L,H)]		
				[(L,T)/(L,H)]	[(L,T)/(L,H)]	
				[(T,L)/(H,L)]	[(T,L)/(H,L)]	[(T,L)/(H,L)]
				[(L,L)/(H,L)]	[(L,L)/(H,L)]	[(L,L)/(H,L)]
				[(T,T)/(H,L)]	[(T,T)/(H,L)]	[(T,T)/(H,L)]
				[(L,T)/(H,L)]	[(L,T)/(H,L)]	[(L,T)/(H,L)]
					[(T,L)/(L,L)]	[(T,L)/(L,L)]
					[(L,L)/(L,L)]	[(L,L)/(L,L)]
						[(T,T)/(L,L)]
						[(L,T)/(L,L)]

APPENDIX H

SUBCONTRACTING OPTION USED VERSUS REALIZED REPLENISHMENT AMOUNTS THROUGH FOUR PERIODS

Table H.1 Subcontracting Option used versus Total Realized Replenishment Amounts through four Periods in the Decentralized Environment

DECENTRALIZED ENVIRONMENT
H / (T,T) / (L,L)

	First Buyer's Realized Replenishment amounts				Second Buyer's Realized Replenishment amounts			
	1st Period	2nd Period	3rd Period	4th Period	1st Period	2nd Period	3rd Period	4th Period
1st sample	500.0	612.5	714.5	622.7	550.0	720.0	650.0	520.0
2nd sample	500.0	612.5	646.5	552.2	550.0	720.0	740.0	719.9
3rd sample	500.0	612.5	697.9	597.1	550.0	600.0	660.0	650.0
4th sample	500.0	553.9	573.3	529.5	550.0	600.0	700.0	650.0
5th sample	500.0	553.9	573.3	541.0	550.0	600.0	650.0	400.0
6th sample	500.0	600.0	714.5	597.1	550.0	650.0	740.0	719.9
7th sample	500.0	600.0	714.5	605.5	550.0	650.0	780.0	650.0
8th sample	500.0	600.0	650.0	595.4	550.0	720.0	780.0	520.0
9th sample	500.0	553.9	573.3	529.5	550.0	600.0	660.0	650.0

Total Realized Replenishment Amounts in Four Periods	Total Order Amounts given to the Subcontractor in Four Periods	Subcontracting option used versus Total Realized Replenishment amounts
4889.8	1340.0	0.27
5041.1	1491.3	0.30
4867.5	1317.7	0.27
4656.7	1106.9	0.24
4368.1	818.3	0.19
5071.6	1521.8	0.30
5050.0	1500.2	0.30
4915.4	1365.7	0.28
4616.7	1066.9	0.23
		average: 0.26

Table H.2 Subcontracting Option used versus Total Realized Replenishment Amounts through four Periods in the Centralized Environment

CENTRALIZED ENVIRONMENT
H / (T,T) / (L,L)

	First Buyer's Realized Replenishment amounts				Second Buyer's Realized Replenishment amounts			
	1st Period	2nd Period	3rd Period	4th Period	1st Period	2nd Period	3rd Period	4th Period
1st sample	500	660	720	470	550	720	520	650
2nd sample	500	660	480	600	550	720	740	720
3rd sample	500	660	650	470	550	480	780	650
4th sample	500	440	480	470	550	520	780	650
5th sample	500	440	650	440	550	480	520	650
6th sample	500	600	720	440	550	650	740	720
7th sample	500	600	720	600	550	650	780	650
8th sample	500	600	650	470	550	720	780	520
9th sample	500	470	520	470	550	520	740	650

Total Realized Replenishment Amounts in Four Periods	Total Order Amounts given to the Subcontractor in Four Periods	Subcontracting option used versus Total Realized Replenishment amounts
4790.0	1060.0	0.22
4970.0	1170.0	0.24
4740.0	1079.6	0.23
4390.0	788.7	0.18
4230.0	630.8	0.15
4920.0	1206.1	0.25
5050.0	1350.0	0.27
4790.0	1032.7	0.22
4420.0	824.9	0.19
		average: 0.21

APPENDIX I

SINGLE FACTOR MODEL RESULTS OF THE SECOND CASE

Table I.1 Tukey's Test Results for the SC Actors in the Decentralized Environment

DM Case	Environment	SC Actor	**TUKEY'S TEST** [(F_{B2},F_M)/(C_B,C_M)] Medium DEVAR		High DEVAR
MANUFACTURER DETERMINES FOR 2ND BUYER	DECENTRALIZED	FIRST BUYER	[(*,*)/(H,*)]		[(*,*)/(H,*)]
				[(*,*)/(L,*)]	[(*,*)/(L,*)]
		SECOND BUYER	[(T,*)/(H,*)]		[(T,*)/(H,*)]
			[(T,*)/(L,*)]	[(T,*)/(L,*)]	[(T,*)/(L,*)]
				[(L,*)/(L,*)]	[(L,*)/(H,*)]
				[(L,*)/(H,*)]	[(L,*)/(L,*)]

MANUFACTURER DETERMINES FOR 2ND BUYER	DECENTRALIZED	MANUFACTURER	[(T,T)/(H,H)] [(T,L)/(H,H)] [(T,T)/(L,H)] [(T,L)/(L,H)] [(L,T)/(H,H)] [(L,L)/(H,H)] [(L,T)/(L,H)] [(L,L)/(L,H)]	[(T,T)/(H,L)] [(T,L)/(H,L)] [(T,T)/(L,L)] [(T,L)/(L,L)] [(L,T)/(H,L)] [(L,L)/(H,L)] [(L,T)/(L,L)] [(L,L)/(L,L)]	[(T,T)/(H,H)] [(T,L)/(H,H)] [(L,T)/(H,H)] [(L,L)/(H,H)] [(T,T)/(L,H)] [(T,L)/(L,H)] [(L,T)/(L,H)] [(L,L)/(L,H)]	[(T,T)/(H,L)] [(T,L)/(H,L)] [(L,T)/(H,L)] [(L,L)/(H,L)] [(T,T)/(L,L)] [(T,L)/(L,L)] [(L,T)/(L,L)] [(L,L)/(L,L)]

Table I.2 Different Results of Duncan's Tests for the Second Buyer in the Decentralized Environment

DM Case	Environment	SC Actor	**DUNCAN'S TEST** [$(F_{B2},F_M)/(C_B,C_M)$] High DEVAR	
MANUFACTURER DETERMINES FOR 2ND BUYER	DECENTRALIZED	SECOND BUYER	[(T,*)/(H,*)] [(T,*)/(L,*)]	[(T,*)/(L,*)] [(L,*)/(H,*)] [(L,*)/(L,*)]

Table I.3 Tukey's Test Results for the First Buyer in the Centralized Environment

TUKEY'S TEST
$[(F_{B2},F_M)/(C_B,C_M)]$

DM Case	Environment	SC Actor	Medium DEVAR	High DEVAR		
MANUFACTURER DETERMINES FOR 2^{ND} BUYER	CENTRALIZED	FIRST BUYER	[(T,L)/(L,H)]	[(L,T)/(L,H)]		
			[(T,T)/(L,H)]	[(T,T)/(L,H)]	[(T,T)/(L,H)]	
			[(T,T)/(H,H)]	[(T,L)/(L,H)]	[(T,L)/(L,H)]	[(T,L)/(L,H)]
			[(T,L)/(H,H)]	[(L,T)/(H,H)]	[(L,T)/(H,H)]	[(L,T)/(H,H)]
			[(T,T)/(H,L)]	[(L,L)/(L,H)]	[(L,L)/(L,H)]	[(L,L)/(L,H)]
			[(L,L)/(H,L)]		[(T,T)/(H,H)]	[(T,T)/(H,H)]
			[(L,L)/(L,L)]		[(T,L)/(H,H)]	[(T,L)/(H,H)]
			[(L,L)/(H,H)]		[(L,L)/(H,H)]	[(L,L)/(H,H)]
			[(L,L)/(L,H)]		[(T,L)/(H,L)]	[(T,L)/(H,L)]
			[(L,T)/(H,L)]		[(L,T)/(H,L)]	[(L,T)/(H,L)]
			[(T,T)/(L,L)]		[(T,T)/(H,L)]	[(T,T)/(H,L)]
			[(T,L)/(H,L)]		[(L,L)/(H,L)]	[(L,L)/(H,L)]
			[(T,L)/(L,L)]		[(L,T)/(L,L)]	[(L,T)/(L,L)]
			[(L,T)/(H,H)]		[(L,L)/(L,L)]	[(L,L)/(L,L)]
			[(L,T)/(L,H)]			[(T,T)/(L,L)]
			[(L,T)/(L,L)]			[(T,L)/(L,L)]

Table I.4 Tukey's Test Results for the Second Buyer in the Centralized Environment

TUKEY'S TEST
$[(F_{B2},F_M)/(C_B,C_M)]$

DM Case	Environment	SC Actor	Medium DEVAR			High DEVAR	
MANUFACTURER DETERMINES FOR 2ND BUYER	CENTRALIZED	SECOND BUYER	[(T,T)/(L,H)]			[(L,L)/(L,H)]	
			[(T,L)/(L,H)]			[(T,L)/(L,H)]	
			[(L,T)/(L,H)]			[(T,T)/(L,H)]	
			[(L,L)/(L,H)]	[(L,L)/(L,H)]		[(L,T)/(L,H)]	
			[(T,L)/(H,H)]	[(T,L)/(H,H)]	[(T,L)/(H,H)]		[(T,L)/(H,L)]
			[(T,T)/(H,H)]	[(T,T)/(H,H)]	[(T,T)/(H,H)]		[(T,T)/(H,L)]
			[(T,T)/(H,L)]	[(T,T)/(H,L)]	[(T,T)/(H,L)]		[(T,L)/(H,H)]
			[(T,L)/(H,L)]	[(T,L)/(H,L)]	[(T,L)/(H,L)]		[(T,T)/(H,H)]
			[(T,T)/(L,L)]	[(T,T)/(L,L)]	[(T,T)/(L,L)]		[(T,L)/(L,L)]
			[(T,L)/(L,L)]	[(T,L)/(L,L)]	[(T,L)/(L,L)]		[(T,T)/(L,L)]
				[(L,T)/(H,L)]	[(L,T)/(H,L)]		[(L,T)/(L,L)]
				[(L,L)/(H,L)]	[(L,L)/(H,L)]		[(L,L)/(L,L)]
					[(L,T)/(L,L)]		[(L,L)/(H,H)]
					[(L,L)/(L,L)]		[(L,L)/(H,L)]
					[(L,T)/(H,H)]		[(L,T)/(H,L)]
					[(L,L)/(H,H)]		[(L,T)/(H,H)]

Table I.5 Tukey's Test Results for the Manufacturer in the Centralized Environment

TUKEY'S TEST
[(F_{B2},F_M)/(C_B,C_M)]

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR	
MANUFACTURER DETERMINES FOR 2ND BUYER	CENTRALIZED	MANUFACTURER	[(T,L)/(H,H)]		[(L,T)/(H,H)]	
			[(T,T)/(H,H)]		[(L,L)/(H,H)]	
			[(L,T)/(H,H)]		[(T,L)/(H,H)]	
			[(L,L)/(H,H)]		[(T,T)/(H,H)]	
				[(L,T)/(L,H)]		[(L,L)/(H,L)]
				[(L,L)/(L,H)]		[(L,T)/(H,L)]
				[(T,L)/(H,L)]		[(T,L)/(H,L)]
				[(T,T)/(H,L)]		[(T,T)/(H,L)]
				[(T,L)/(L,H)]		[(L,T)/(L,H)]
				[(T,T)/(L,H)]		[(L,L)/(L,H)]
				[(L,T)/(H,L)]		[(T,L)/(L,L)]
				[(T,L)/(L,L)]		[(L,L)/(L,L)]
				[(L,L)/(H,L)]		[(T,T)/(L,L)]
				[(T,T)/(L,L)]		[(T,L)/(L,H)]
				[(L,T)/(L,L)]		[(L,T)/(L,L)]
				[(L,L)/(L,L)]		[(T,T)/(L,H)]

Table I.6 Different Results of Duncan's Tests for the First Buyer in the Centralized Environment

DUNCAN'S TEST

$[(F_{B2},F_M)/(C_B,C_M)]$

DM Case	Environment	SC Actor	Medium DEVAR		High DEVAR			
MANUFACTURER DETERMINES FOR 2^{ND} BUYER	CENTRALIZED	FIRST BUYER	[(T,L)/(L,H)]		[(L,T)/(L,H)]			
			[(T,T)/(L,H)]		[(T,T)/(L,H)]	[(T,T)/(L,H)]		
			[(T,T)/(H,H)]	[(T,T)/(H,H)]		[(T,L)/(L,H)]	[(T,L)/(L,H)]	
			[(T,L)/(H,H)]	[(T,L)/(H,H)]			[(L,T)/(H,H)]	[(L,T)/(H,H)]
			[(T,T)/(H,L)]	[(T,T)/(H,L)]			[(L,L)/(L,H)]	[(L,L)/(L,H)]
			[(L,L)/(H,L)]	[(L,L)/(H,L)]			[(T,T)/(H,H)]	[(T,T)/(H,H)]
			[(L,L)/(L,L)]	[(L,L)/(L,L)]			[(T,L)/(H,H)]	[(T,L)/(H,H)]
			[(L,L)/(H,H)]	[(L,L)/(H,H)]			[(L,L)/(H,H)]	[(L,L)/(H,H)]
			[(L,L)/(L,H)]	[(L,L)/(L,H)]			[(T,L)/(H,L)]	[(T,L)/(H,L)]
			[(L,T)/(H,L)]	[(L,T)/(H,L)]			[(L,T)/(H,L)]	[(L,T)/(H,L)]
			[(T,T)/(L,L)]	[(T,T)/(L,L)]			[(T,T)/(H,L)]	[(T,T)/(H,L)]
			[(T,L)/(H,L)]	[(T,L)/(H,L)]			[(L,L)/(H,L)]	[(L,L)/(H,L)]
			[(T,L)/(L,L)]	[(T,L)/(L,L)]			[(L,T)/(L,L)]	[(L,T)/(L,L)]
			[(L,T)/(H,H)]	[(L,T)/(H,H)]			[(L,L)/(L,L)]	[(L,L)/(L,L)]
			[(L,T)/(L,H)]	[(L,T)/(L,H)]			[(T,T)/(L,L)]	[(T,T)/(L,L)]
				[(L,T)/(L,L)]				[(T,L)/(L,L)]

Table I.7 Different Results of Duncan’s Tests for the Second Buyer in the Centralized Environment

DM Case	Environment	SC Actor	**DUNCAN'S TEST** [$(F_{B2},F_M)/(C_B,C_M)$] Medium DEVAR			High DEVAR			
MANUFACTURER DETERMINES FOR 2^{ND} BUYER	CENTRALIZED	SECOND BUYER	[(T,T)/(L,H)]			[(L,L)/(L,H)]			
			[(T,L)/(L,H)]			[(T,L)/(L,H)]			
			[(L,T)/(L,H)]			[(T,T)/(L,H)]			
			[(L,L)/(L,H)]	[(L,L)/(L,H)]			[(L,T)/(L,H)]		
				[(T,L)/(H,H)]	[(T,L)/(H,H)]			[(T,L)/(H,L)]	
				[(T,T)/(H,H)]	[(T,T)/(H,H)]			[(T,T)/(H,L)]	[(T,T)/(H,L)]
				[(T,T)/(H,L)]	[(T,T)/(H,L)]			[(T,L)/(H,H)]	[(T,L)/(H,H)]
				[(T,L)/(H,L)]	[(T,L)/(H,L)]			[(T,T)/(H,H)]	[(T,T)/(H,H)]
					[(T,T)/(L,L)]				[(T,L)/(L,L)]
					[(T,L)/(L,L)]				[(T,T)/(L,L)]
					[(L,T)/(H,L)]				[(L,T)/(L,L)]
					[(L,L)/(H,L)]				[(L,L)/(L,L)]
					[(L,T)/(L,L)]				[(L,L)/(H,H)]
					[(L,L)/(L,L)]				[(L,L)/(H,L)]
					[(L,T)/(H,H)]				[(L,T)/(H,L)]
					[(L,L)/(H,H)]				[(L,T)/(H,H)]