A DECISION SUPPORT SYSTEM FOR CONSUMER DRIVEN SUPPLY NETWORKS

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When the solution is simple, God is answering.

Albert Einstein

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ABSTRACT

A DECISION SUPPORT SYSTEM FOR CONSUMER DRIVEN SUPPLY NETWORKS

In this thesis, a decision support system is constructed to manage tactical and strategic level decision in a consumer driven supply networks. Decision making process includes many decision makers, multiple objectives, and high complexity most of the time. Therefore, senior and top management seek for a tool to handle these problems. This decision support system should have extended functionality that enable customization, optimization, what- if analysis. Since the investigated problem is multi-objective by nature, Pareto analysis and developing efficient frontiers for different decision measures becomes vital. The motivation of this study is not to develop the best optimization model that solves supply network problems but to design a tool that manages these large scale optimization models for real life applications where the decision-maker has a limited knowledge or time to handle the very much details of the decision making process. In addition to these, synchronizing several functions that define different portions of the entire supply network with their objectives, parameters and constraints is crucial. Our supply network model includes several generic concepts from market planning, promotion planning, rough cut capacity planning, demand planning and material resource planning, Together with these synchronized sub- functions, decision nodes that enable top managers to create their own scenarios at the higher level and to manage the model are constructed.

ÖZET

MÜŞTERİ ODAKLI TEDARİK ZİNCİRLERİ İÇİN KARAR DESTEK SİSTEMİ

Bu çalışmada, müşteri odaklı tederik zincilerinde taktik ve stratejik seviye karar verme problemlerini yönetmek amacı ile bir karar destek sistemi geliştirilmiştir. Çoğu zaman karar verme süreçleri farklı amaçları olan çok sayıda karar vericiler ve karmaşık bir yapı içermektedir. Bu yüzden üst yönetim bu problemleri yönetmek için uygun bir araca ihtiyaç duymaktadır. Bu karar destek sistemi eniyileme, kişiselleştirme ve varsayım analizi gibi genişletilmiş özelliklere sahip olmalıdır. İncelenmekte olan problem yapısı gereği birden fazla karar vericinin amaçlarını içermektedir. Bu sınıftaki problemler için pareto analizi ve farklı karar değişkenleri için en verimli çözümlerin incelenmesi kaçınılmazdır. Bu çalışmadaki amaç tedarik ağı problemlrinde en iyi sonuç veren eniyileme modelinin geliştirilmesi değildir. Gerçek problemlerde, karar vericiler modelleme ve teknik detay hakkında yeterli bilgi ya da yeterli zamana sahip olmayabilirler. Bizim amacımız gerçek problemlerde kullanılan büyük ölçekli eniyileme modelleirnin yönetilmesi ve yukarıda bahsedilen zorlukların ortadan kaldırılması için bir araç geliştirmektir. Bütün tedarik ağının farklı bölümlerini ifade eden fonkisyonları amaçları, değişkenleri, kısıtları ve parametreleri ile yaratıp aralarındaki ilişkileri kurmak çok önemlidir. Kurmuş olduğumuz tederik ağı modeli pazar planlama, promosyon planlama, kaba kapasite planlama, talep planlama, imalat kaynakları planlaması gibi alanlardan genel kavramları içermektedir. Bu fonksiyonlar ve kavramlar ile birlikte, üst düzey yöneticilerin kendi senaryolarını, üst seviyede tanımlayabilecekleri araçlar geliştirilmiştir.

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LIST OF SYMBOLS/ABBREVIATIONS

a	Process index
a_d^D	Process which derives d $(d \in DD)$
a_u^U	Process of usage u $(a_u^U \in A)$
A	Set of processes $(a \in A)$
A_{it}^I	Set of processes feeding inventory i at time t
A_p^P	Set of processes of part p
A_s	Set of supply process $a_s \in A_s \wedge A_s \subset A$
b	Market Index
B	Set of Markets $(b \in B)$
BC_c^C	Buying capacity of customer $c \in C$ at a specific period t_c^C
c	Customer Index
c_d^D	Customer that drives demand d $(c_d^D \in C)$
C	Set of Customers $(c \in C)$
C_b^B	Customer portfolio of market b $(C_b^B \subset C)$
C_c^C	Set of child customers of customer $(c \in C)$
C_g^G	Set of customers that drive demand for product group $(g \in G)$
C_r^R	Set of child resource groups of resource group $(r \in R)$
CS	Opportunities set
d	Demand index
d_s^S	The demand which is satisfied by delivery s $(d_s^S \in D)$
D	Set of demands $(d \in D)$
D_c^C	Set of demands drived by customer c $(D_c^C \subset ID)$
D_g^G	Set of demands belonging to product group g
DD	Set of dependent demands $(DD \subset D)$
DD_a^A	Set of dependent demands derived by process a
fc_{ph}^P	Freight cost per product through a specific path h in a specific period t

g	Product group index
G	Set of product groups ($g \in G$)
G_b^B	Set of product groups belonging to market b ($G_b^B \subset G$)
h	Path index
hc_{pit}^P	Inventory handling cost per product p in a specific storage location i in specific period t
H	Set of paths ($h \in H$)
H_p^P	Set of paths of part p
HI_i^I	Set of paths leaving inventory i
HO_i^I	Set of paths with destination inventory i
i	Inventory index
i_a^A	Output inventory of process a ($i_a^A \in I$)
i_d^D	Delivery inventory of demand d ($i_d^D \in I$)
I	Set of inventories ($i \in I$)
I_p^P	Set of inventories of part p
ID	Set of independent demands ($ID \subset D$)
if_h^H	Starting inventory of path h
it_h^H	Ending inventory of path h
K_{rt}^R	Independent capacity of resource group $r \in R$ at period $t \in T^+$
L_a^A	Lead time of process a
m_d^D	BOM multiplier: Quantity of part p_d^D required for unit a_d^D ($d \in DD$)
m_u^U	Capacity of resource group r_u^U to be consumed per unit by process a_u^U
mc_{at}^A	Material unit cost in a specific period $t \in T^+$ where $a \in A_s$
MD_{pt}^P	Market Sales Volume of Product $p \in P$ at period $t \in T^+$
MD_{gc}^G	Market Sales Volume of Product Group $g \in G$ for customer c at a specific period t_c^C
MD_{bc}^B	Market Sales Volume of Business $b \in B$ for customer c at a specific period t_c^C
oc_{rat}^R	Regular usage cost of resource r by process a in specific period $t \in T^+$

p	Part index
p_a^A	Part of process a ($p_a^A \in P$)
p_d^D	Part of demand d ($p_d^D \in P$)
p_i^I	Part of inventory i ($p_i^I \in P$)
P	Set of parts ($p \in P$)
P_c^C	Set of parent customers of customer c
P_g^G	Set of products belonging to product group g
P_r^R	Set of parent resource groups of resource group ($r \in R$)
pc_{at}^A	Process cost of process a per product in a specific period $t \in T^+$
PP_c^C	Product group portfolio (set) of customer c ($PP_c^C \subset P$)
PP_b^B	Product group portfolio (set) of business b ($PP_b^B \subset P$)
PS	Production possibilities set
q_a^A	Quantity of process a at a specific period t_a^A
q_d^D	Quantity of demand d ($d \in ID$) at a specific period t_d^D
$^+q_d^D$	Quantity of Additional Demand ($d \in ID$) for product p_d^D and customer c_d^D at a specific period t_d^D
$^-q_d^D$	Quantity of Unsatisfied Demand ($d \in ID$) for product p_d^D and customer c_d^D at a specific period t_d^D
q_g^G	Quantity of Product Group demanded at a specific period t_d^D
q_b^B	Total Quantity of product supply for business b at a specific period t_d^D
q_{ht}^H	Quantity delivered over path h at period t
q_{it}^I	Quantity stored in inventory i at the end of period t ($t \in T$)
q_s^S	Quantity of delivery s at a specific period t_s^S
q_u^U	Percentage of regular resource usage at a specific period t_u^U ($t_u^U > 0$)
r	Resource group index
r_u^U	Resource group of usage u ($r_u^U \in R$)
rc_{rat}^R	Regular usage cost of resource r by process a in specific period $t \in T^+$

R	Set of resource groups ($r \in R$)
s	Delivery index
sc^{P}_{pit}	Inventory storage cost per product p in a specific storage location i in a specific period t
S	Set of deliveries ($s \in S$)
S^{D}_{d}	Set of all deliveries that can satisfy demand d
S^{I}_{it}	Set of deliveries from inventory i at period $t \in T^{+}$
t	Period index
t^{A}_{a}	Completion time of process a ($t^{A}_{a} \in T^{+}$)
t^{C}_{c}	Period of customer c ($t^{C}_{c} \in T^{+}$)
t^{D}_{d}	Period of demand d ($t^{D}_{d} \in T^{+}$)
t^{S}_{s}	Period of delivery s ($t^{S}_{s} \in T^{+}$)
t^{U}_{u}	Period of usage u ($t^{U}_{u} \in T^{+}$)
T	Set of periods ($t = 0, 1, ..., \|T\|$)
T^{+}	Set of periods ($t = 1, 2, ..., \|T\|$)
$u^{R}_{r_1 r_2 t}$	Amount of capacity of group r_1 used by group $r_2 \in P^{R}_{r_1}$ at period $t \in T^{+}$.
u	usage index
U	Set of usages ($u \in U$)
U^{A}_{a}	a Set of resource group usages during process a
U^{A}_{ar}	Set of usages of resource group r during process a
U^{R}_{rt}	Set of usages of resource group r at period $t \in T^{+}$
w^{G}_{gc}	Market Penetration of Product group g for customer c
w^{G}_{bc}	Market Penetration of business b for customer c
Z^{I}_{i}	Initial inventory stored in i
α^{C}_{cd}	Discount cost for customer $c \in C$ per demand $d \in D^{C}_{c}$
ε^{C}_{cd}	Inventory holding cost for customer $c \in C$ per demand $d \in D^{C}_{c}$
η^{C}_{cd}	Period end bonus cost for customer $c \in C$ per demand $d \in D^{C}_{c}$
ρ^{C}_{cd}	Unsatisfied demand cost for customer $c \in C$ for demand $d \in D^{C}_{c}$

χ_{cd}^{C} Additional demand cost for customer $c \in C$ for demand $d \in D_c^C$

1. INTRODUCTION

In this thesis, a decision support system that provides a multi-objective decision aid for manufacturing companies is studied. The decision support system, DSS, is designed to assist different levels of managers in the industrial organization. Industrial organizations have various internal and external dynamics that shape their corporate strategies. Interaction of these dynamics are complicated most of the time and the decision making problematic becomes complex in nature. DSS studied in this thesis aims to corporate decision makers for their complicated decision making process.

In the literature [1], [2], [4], [5], it stated that most real-world decision-making problems include

- Multiple, different and conflicting objectives
- Hierarchy of objectives. In modeling, it is important to identify this hierarchy of objectives
- Comparing and trading off objectives that belong to different levels
- Integrating common sense with empirical, quantitative, normative and descriptive analysis
- Improving the decision making process in complex systems
- The perception of the decision makers
- The biases of the modeler
- Accuracy of the Database
- Negotiations between the decision makers
- Complicated constraints for the internal and external organization

On the other hand a decision support system, DSS, should be in line with these requirements above if its aim is to provide perfect guidance for the decision making process. The end users are neither programmers nor people trained in computers and they demand friendly tools and procedures for easy use [6]. A DSS should have the following features, according to Turban and Aronson [7], and Mallach [8]:

A Decision Support System

- aims to assist managers in making decisions
- is based on a data processing environment
- can resolve structured, semi-structured, or non structured type of problems according to the point of view of the decision makers
- is a flexible system
- is capable of giving support and providing ad hoc analysis of data and decision models, in the search to obtain efficient results in long, mid and short-term planning.

According to Shimuzu [6], a DSS is computer system made up of different interactive components. It should

- allow communication between users
- allow communication between sub-systems
- structure and execute appropriate models to solve different type of problems
- allow sensibility analysis of the result of decision. The user should be able to ask what- if questions
- serve managers at different levels
- allow decisions by an individual or group
- be able to make both sequential and interdependent decisions;
- provide a variety of decision making styles
- be user friendly
- seek efficacy, capacity to produce desire effect, and not efficiency
- facilitate the formulation of the problem by the end user, and
- allow the analysis of results.

Decision Support Systems should be developed in order to increase competitive power of the companies. Together with lean, robust and agile systems, firms are seeking consumer oriented supply networks. Today, consumer oriented supply networks compete in the market place not the companies. Therefore, it is important to improve the efficiency of the decision-making process, to provide better administrative control and to enhance the communication between the sub functions. Decision support system helps the decision makers in the analysis of existing alternatives, optimizing alternatives and making combinations of the decision alternatives.

In this thesis, the focus area is to support corporate strategy making in both tactical level planning and strategic level planning. A corporate strategy should meet the opportunities and threats both in the organization's external and internal environment. Forces shaping the industry and the macroeconomic environment are the external dynamics for the corporate strategy. On the other hand, a corporate strategy should have an internal focus related with internal performance measures of the business. All these forces determine the competitive power of a company and the objective of a corporate strategy should be to modify these competitive forces in a way that improves the position of the organization and to maximize the utilities of the stakeholders in a company.

Stakeholders in a company may include

- **Shareholders Equity:** Shareholders tend to have the maximum profit on a given period together with the highest operational and financial performance. Another significant point for the shareholders is the direction of company, namely corporate strategies in the long run
- **Government Equity:** Governmental authorities expect from companies to pay the maximum amount of tax and not to violate legislations.
- **Senior Management Equity:** Maximum of Key Performance Indicators and satisfaction of targets in different fields such as sales, finance, production, warehouse etc.
- **Customer Equity:** Customers want to have maximum quality and value at a minimum price. Maximum customer care should be provided to the customer before and after sales.
- **Creditors Equity:** Creditors want to provide credits to companies with the highest credit score that depends on several parameters. They also track the new business contracts and liquidity level of the company.

- **Community Equity:** Communities are satisfied whenever they get jobs and involvements. Sensitivity to the environmental and cultural issues are also add value to this equity

Each of the stakeholders has different objectives, some of these objectives may conflict, and some of these objectives may coincide.

In a business environment when the competitive forces, defined by Porter in 1985 [3], are concerned, stakeholders and the company feel more pressure due to

- **Threat of new entrants:** It is directly related to the entry barriers of the industry. If the barriers to entry are low, the industry will face a more threat of new entrants. The risk level for a particular industry increases. The competition in an industry gets higher and new entrants may change market penetration, prices, brand loyalty, brand recognition etc. These changes make the existing companies alter their corporate strategies.
- **Threat of substitutes:** Alternative products with lower prices of better performance could potentially attract a proportion of market volume and reduce the potential sales volume for existing players.
- **Increasing bargaining power of suppliers:** The buying industry often faces a high pressure on margins from their suppliers. The relationship to powerful suppliers can potentially reduce strategic options for the organization
- **Increasing bargaining power of customers:** This case determines the pressure on profit margins and sales volume of customers
- **Competitive rivalry between existing players:** High competitive pressure results in pressure on prices and margins. Therefore, profitability for every company in the industry tends to decrease.

By analyzing these forces, management can decide how to influence or to exploit particular characteristics of their industry, competitive power of the company and benefit of the stakeholders. There are many participants of this business game and every actor may have a different objective to be maximized. Nevertheless, the bottom-line should be to maximize benefits of the organization.

Today, an organization is not interested only in the best alternative of decision, but it is interested in knowing a set of good enough or best possible alternatives considering many aspects or multiple criteria such as quality aspects, stakeholders equity, environmental risk and so on. Therefore, it is often necessary to analyze each alternative in light of its potential impact on several goals. Besides, the relationship between the alternatives is complex most of the time and it is hard to define their impacts on the organization's goal that is not known in advance due to the complexity. Conventionally, most organizations make a decision based on successful past experiences. This type of decision-making leads to refinement but it can skip the new solutions that are better than the previous ones. On the other hand, solutions to multi-objective optimization problem with multiple decision makers are often reached through negotiation. When the system is complex in order to judge every trade off between the alternatives, negotiation process or the human behavior becomes more influential in finding win-win strategies. Such compromise solution may end up with non-win-win solutions even it violates some of the constraints. If the human behavior effect has more impact on the decision making process, some implementation problems might also occur. A decision-maker in a losing group may be influential enough to sabotage the compromise solution and prevent its implementation. If a stalemate arises and a compromise solution is not achievable, the scope of the problem may be broadened. Finally, the no decision case could be costly.

As previously, mentioned, human behavior is very influential on the decision-making processes. Optimal solutions are for ideal cases and since real life is not ideal, a multiple decision aid tool such as DSS should not focus on the optimum solutions and waste resources to find the optimums. A multiple decision aid tool should include the interaction between the decision maker(s) and the DSS, develop a causal relationship among the various systems' input and outputs, determine the preferences of each decision maker in order to arrive at his or her indifference band and preferred solution, generate an appropriate set of non inferior (Pareto Optimal) solutions and their associated trade-off

Management may want to react and alter corporate strategies. Decision makers may ask several questions, want to make assessments between the alternatives and clarify the trade-offs. The Information Systems department may not meet the company's diversity of needs or to answer ad hoc questions raised by the managers. Since the company should react the changing environment as soon as possible and need to optimize numerous business operations and reassess the corporate strategies a DSS is needed for most of the companies.

Globalization and sustained growth of international trade has increased competition in most of the markets. Today, virtually all major firms have a significant and growing presence in business outside their country of origin. Transfers between subsidiaries of the same company account for most of the trade between industrialized countries. Many companies recognize the opportunities for selling their products in several new markets. The main focus for an enterprise is to stabilize the demand, price, cost and risk fluctuations for their certain business areas. Better logistics, removal of trade barriers, opportunities in the emerging markets, improved communications in businesses and among consumers are the main factors behind scenes of this new world approach.

‘Value’ in today’s context does not just mean value for money, although that is certainly a critical determinant of purchase for many buyers; it also means perceived benefits. Organizations create value for their customers either by increasing the level of ‘benefit’ they deliver or by reducing the customers’ costs

Because there are such benefits, many people think that global operations are inevitable. A global company sees the world as a single market and manages its subsidies from one central location. In this sense, implementation of portfolio logic through out the value chain becomes important when the profitability and sustainability issues are concerned. Therefore, international firms should focus on the efficient market, customer, product and supplier portfolios. Moreover, trade-offs between these portfolio alternatives should be examined carefully in order to construct the best corporate strategy. The key point to note is that these benefits are essentially perceptual and that they will differ by customer. The ‘total cost of ownership’ reflects all the costs associated with the relationship, not just the price of the product such as the customers’ cost of carrying inventory.

In this thesis, we are going to present a decision support system for consumer driven supply networks. We are going to divide the value change from supplier to consumer into sub-functions and present an interface for the use of decision makers in their decision-making process. Sales and Marketing Function together with the Supply Network Function and Cost Function are the main components of the DSS. These functions aim to construct a link between supply network and sales and marketing systems. A linear mathematical model forms the infrastructure of these functions and via several cost parameters and decision variables, decision-makers are able to develop their own problem of interest, include their perception and can make comparisons with scenario analysis.

Our decision support system will gain ground in the next section as follows:

- Section 2 defines the problem, main decision framework and its subparts. You can find breakdown of the functions and concepts that underlies the mathematical model of the decision support system in this section.
- Section 3 sets the assumptions for each featuring function of the mathematical model.
- Section 4 provides a comprehensive literature survey. Relevant literature on supply network planning and decision support systems will be reviewed in this section. We will present basic decision support systems, modeling tools related with the supply chain planning problems, some marketing literature including promotion planning and pricing.
- Section 5 represents the mathematical model of our decision support system. On top of defined framework and assumptions, related constraints and objectives of the mathematical model will be defined in this part.
- In section 6, we represent our modeling and application practices for our DSS. Development environment, object-oriented model of the DSS and design of the interface can be found in this section.

2. PROBLEM DEFINITION

As mentioned in previous sections, multi-national companies see the world as a single market. This strict definition should be relaxed to gain some reality. When the whole world is behaved like single market, there should be a hierarchy between the choices. A multi-national company should fragment this single market to sub-markets and their customers, products and supply network. Therefore, they should focus on the efficient market, customer, product and supplier portfolios. Moreover, trade-offs between these portfolio alternative should be examined carefully in order to construct the best corporate strategy.

Every hierarchical category of this single market, whole world, has some characteristics, priorities, constraints and decision makers. Relation between all these categories, in other words the stakeholders of the company, can be complicated and some intrinsic opportunities may exist among these relations. Every stakeholder has an objective to satisfy and these objectives may conflict with each other. A well-developed corporate strategy should find a feasible solution, not the optimal. Optimality is a theoretical concept and an optimal solution of a business model may not be applicable in real cases. Hierarchical categories of the single market create a hierarchy between decision makers. Every decision maker should be able to think the trade-off between its decision alternatives and at the end a win-win solution, if possible, should be created. If a non win-win case is the solution, it may cause some execution problems.

The best results clearly come from considering all aspects of the decision- makers in a single, integrated function. This gives a broader and more inclusive view of the system parts with relevant activities coordinated under the umbrella of a unified function. Functions in a multi-national enterprise can be summarized as below:

- Sales and Marketing Function
- Logistics Function
- Finance Function

- Manufacturing Function
- Human Resources Function
- IT Function
- R&D Function
- Public Relations Function

In this thesis, we will not focus on all of the functions. Our stand point can be summarized as

- *Sales and Marketing Function:* External and internal market dynamics, customer and consumer details and expectations are considered under this function
- *Supply Network Function*: It is the combination of logistics and manufacturing function.
- *Cost Function:* Mainly includes cost accounting and cost predictions of the whole system

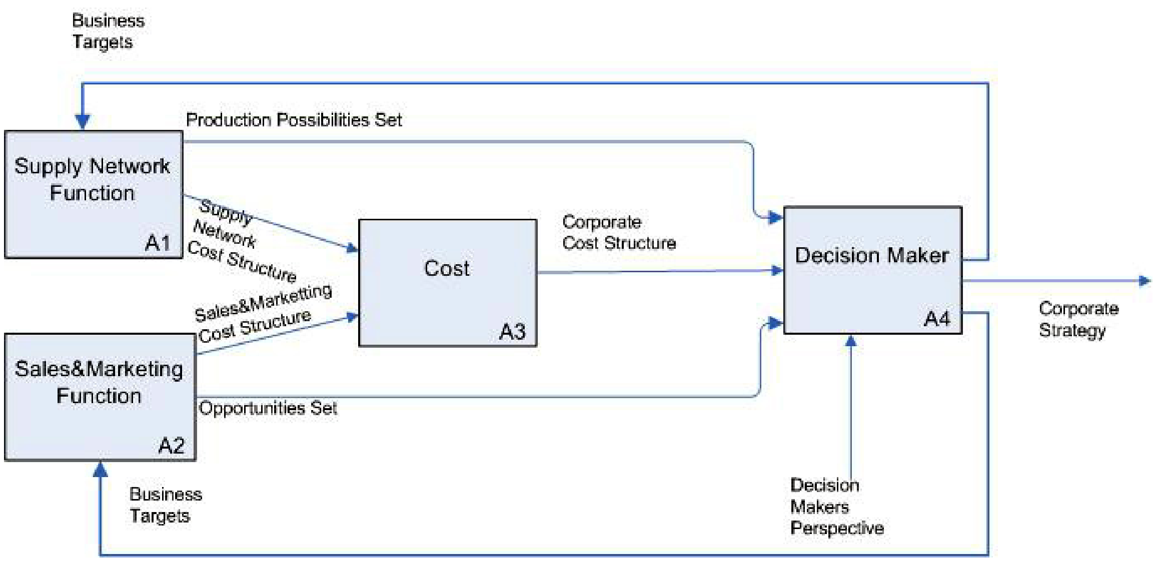


Figure 2.1. Main decision framework

Figure 2.1 represents the main decision making process that we propose in this thesis. Section 5 describes Supply Network Function, Sales & Marketing Function and Cost Function in more detail with their mathematical definitions.

Both supply network function and sales & marketing function should follow business targets during their internal processes. Business targets are set after long analysis of internal and external environments. Business targets are the consequences of corporate strategies and business needs. Moreover, they define the objectives of sub-functions.

When the corporate level decision making is concerned, the ultimate purpose of supply network function is to provide production possibilities set and its related supply network cost structure. Sales & Marketing function creates business opportunities set together with the cost structure. Both the sales & marketing cost structure and Supply network cost structure construct the cost function. Cost function determines the corporate cost structure.

Production Possibilities Set provides a set of possible production levels of different products. A set of alternative product-mixes, production possibilities set, provides different decision opportunities to the decision maker. On top of, these alternatives are derived using supply network function that includes several regarding constraints. When generating the production possibilities set and its related cost structure, supply network function considers different layers of the business environment such as manufacturing, distribution, inventory handling and resources.

Business Opportunities set provides a set of candidate demands to be satisfied. Considering the detailed macroeconomic analysis, market forecasts, customer structure and business structure, sales & marketing function provides a set of candidate demands to be satisfied, opportunities set, and cost structure.

When the production possibilities set, business opportunities set and the corporate cost structure are determined, making a corporate level decision-making becomes possible. Decision making process sets profit margins, market portfolios, customer portfolios and product portfolios for the following fiscal year. Making different trade-off analysis between the alternatives of these portfolios, decision makers are able to set the efficient frontier and in turn, they are able to define the corporate strategy and business targets. Please note that we define the cost as an independent function from the others. One of the purposes of this decision making process is to make various trade-off analysis. For instance, a decision maker may want to measure difference of the impact between cost scenarios to the whole system or know the bottlenecks in the supply network for different marketing strategies. We believe that classification is inevitable for appropriate decision making because of complexity, measurement and forecasting problems. Every main function defined in the process and their sub-functions have inputs and outputs. Inputs and Outputs of these functions can be tangible or intangible. For instance, logistics essentially offers an intangible service and it is hard to measure this service. If we look at this fact from a decision support point of view, this one of the problems that companies face during decision-making. Beyond the intangibility of the services, some complexity problem may exist when measuring these inputs and outputs. Separating the performance of logistics from both other internal operations and external operations is a performance measurement problem due to complexity. Late deliveries to customers, might be caused by poor logistics but they might also be caused by poor demand forecasts, or production problems, traffic congestion, or a whole range of other factors which logistics managers cannot control or even influence.

Input measures should reflect the major factors that can be affected within the company and output measures should be the consequences of these major changes and depict the value-added to the stakeholders. The ultimate performance measures on which the stakeholders judge the business are not open to direct action. We cannot act directly on sales revenue since it has a correlation with the macroeconomic values. Moreover, a company cannot directly increase the sales revenue without increasing inventory availability and service turnaround. When the inventory levels of the total supply chain is considered, a company should deal with its demand forecasting accuracy, horizon inventory record accuracy and safety stock levels. If the profit margins, costs and lead times are concerned supply network should be analyzed.

Once the business and corporate level strategies are examined and their effects on the functions listed above are clarified, results should be used to set objectives of each function. Every level of hierarchy may have different strategic plans for the future that are represented by the objective functions. After setting the objectives, decision makers may use the efficient frontier or Pareto analysis to find final corporate strategy for his/her company. In order to find Pareto efficient solutions, decision makers should use the trade-off analysis.

2.1. Supply Network Function

Customer satisfaction has become more significant. In order to have an improved competitive position, a company should optimize its supply network and should be able to account its impacts on the customer value.

Supply network function is composed of different levels of sub-functions:

- Production
- Delivery
- Resource
- Inventory Handling

Together with other factors, we believe that each of these has a significant impact on quality of customer service. In other words, these are integral parts of demand and customer satisfaction process. When the whole company structure is considered, analyzing the effects of each function to the system becomes cumbersome. Decision maker should be able to see the impacts of any minor change in one of these functions to the whole system. Each function has some variable input parameters, corporate level inputs that are hard to change in short-term periods and strategic level inputs that need capital investment. Most of the time, corporate tactical level decision-making is updated from fiscal year to fiscal year or at most replenished in 18 months time. Therefore, all these data should be provided for every period. Period length may vary with business need. We assume that companies have an MRP system that provides real-time variable input data to these functions.

By classifying each Supply Network Function as a sub-function and implementing the object-oriented thinking, we provide a modular structure to the decision making process. This modular structure enables scenario-based approach to the decision makers. Several input scenarios may be defined for each supply chain function. Please note that we define the cost as an independent function in order to increase flexibility of our decision support system. Users may construct different scenario combinations in order to ask what-if questions to analyze the impacts of each input. Holding some of the scenarios constant and changing the investigated functions, decision makers are able to make scenario analysis that is a fundamental approach for most of the decision-making processes.

Table 2.1. Scenario composition

	Sub-function Scenarios				
Supply Network	**Production**	**Delivery**	**Resource**	**Inventory Handling**	**Cost**
SNS1	PrdS1	DlvryS1	RS1	IHS1	CS1
SNS2	PrdS1	DlvryS2	RS2	IHS2	CS2
SNS3	PrdS1	DlvryS2	RS1	IHS1	CS1
SNS4	PrdS2	DlvryS3	RS1	IHS2	CS1
SNS5	PrdS2	DlvryS3	RS2	IHS1	CS1
SNS6	PrdS3	DlvryS1	RS1	IHS1	CS2

In the above set-up we have

- Production Scenarios of PrdS1, PrdS2 and PrdS3.
- Delivery Scenarios of DlvryS1, DlvryS2, DlvryS3
- Resource Scenarios of RS1, RS2
- Inventory Scenarios of IHS1, IHS2
- Cost Scenarios of CS1, CS2

Any of the inputs may be different in one of these scenarios.

As mentioned above, we define four sub-functions inside the supply network function.

2.1.1. The Production Function

The production function may have several objectives to be satisfied. By nature of multi-objective decision-making, there exist several trade-offs between these objectives. In this framework, the production function should be thought as production planning function. Based on the resource constraints, available inventory on hand and production constraints, its ultimate goal is to make an optimum production plan. We should provide a short explanation here for the inventory on hand. The production function both requires resource material inventory and finished product inventory on hand. Furthermore, production function requires detailed supplier information. Manufacturing companies do have both local and global suppliers for specific materials. Each supplier has different service of quality, lead-time, material quality, reliability and cost. Each supplier is provided as an input to the production function including their defined properties. Then, production function is able to choose the optimum supplier according to defined objective.

Other requirements for the production function are traditional as in other planning systems in the literature. These inevitable constraints are production constraints based on the type of business, material and product definitions, production orders, inventory levels and resource constraints. Each datum that is provided to the production function can be per product group or product based on the need. User can also define resource groups and different storage locations.

The ultimate goal of most of the manufacturing companies is to produce any variant of its product in any quantity, namely flexibility. Manufacturing enterprises should be able to produce every product with different qualities at low quantities. In order to increase customization and decrease inventory levels, they tend to decrease lot size and response time. At the end, flexibility is increased in order to increase customer and demand satisfaction. It is known in advance that this strategy may cause diseconomies of scale. Please note that, production lead-time, response time and product price are key elements of customer service quality and a decision maker should be able to analyze the trade-offs. On the other hand, especially multi-national companies' objective is to create focused enterprises and produce vast amount of special product groups in order to sell in the "Single Market". There is a great trade-off here in terms of manufacturing costs and customer satisfaction.

In ideal case, if the production lead-time is zero maximum flexibility is achieved by zero inventories and omitting the forecasting process. Whenever a customer order is received, it is produced with immediately and delivered to the customer instantaneously if the logistics lead-time is zero.

By using the production function, decision makers have the chance to control inventory levels per product group, resource utilization, and production costs and demand satisfaction. The user can also want to minimize operation production planning measures such as set-up times, scrap cost and lead times.

Production function requires

- The production constraints including every details about the production shop floor such as:
  - Successor, predecessor relations between the processes
  - Alternative resource capacity requirements of processes
  - Process lead times,
  - Process scrap ratios,
  - Process capacity
- Material and product definitions,
  - Bill of Materials
  - Alternative resource and packing materials for a given product
  - Product parent-child relations.
  - Product Specifications
  - Material Specifications
  - Quality Aspects
- Inventory levels
  - Available resource and packing materials. Provided by an MRP system such
  - Inventory record accuracy
- Forecasts and blanket orders provided by an MRP system.
- Supplier Details
  - Bargaining Power of Supplier
  - Supplier lead time
  - Supplier reliability
  - Material Cost
  - Quality of service

Possible objectives of production function can be summarized as minimization of production costs and inventory levels, maximization of demand satisfaction and resource utilization

When the whole system is concerned companies do not only have the manufacturing costs but also have the logistics costs including transportation, warehouse, backorder, administrative and overhead costs. Together with manufacturing costs, these costs should also be minimized in order to increase quality of customer service level by creating flexibility in the EBITDA margin of the company. In this thesis, production function is focused on tactical level production planning rather that operational planning. With this focus, production function tries to point out maximization of the capacity utilization and return the product-mix that gives the best feasible result in terms of capacity utilization and production costs. Above measures are rather in-process measures that are tracked more in the operational production planning. Please note that, a preferred production function should combine both in-process and output measures effectively in order to satisfy consistency between objectives, processes and constraints.

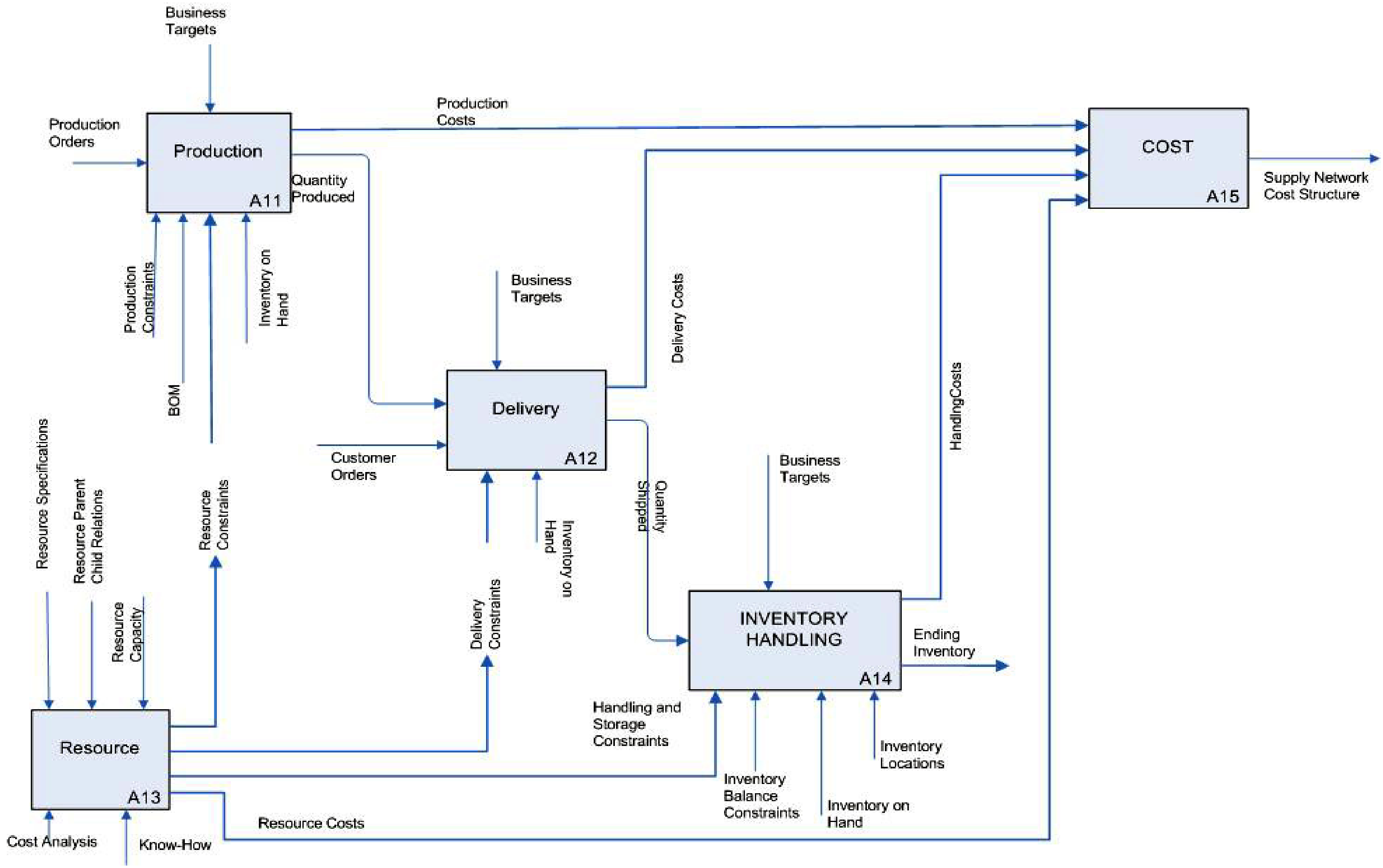


Figure 2.2. Framework of supply network function

2.1.2. The Delivery Function

In this context, delivery function mainly focuses on the delivery of finished products to the customers and therefore tactical level shipment planning. Intra-company decisions and figures are not accounted in this function. Delivery function is depended on the production and sales & marketing functions. Delivery function should focus on path and type of the shipment. A company may have more than one storage location and finished products may be scattered through out these locations. Companies have both domestic and export customers and each customer may have specified products. Delivery function should find the optimum shipment plan based on the business constraints. Please not that, decision support system that is proposed in this thesis, aims to solve tactical and strategic level problems. Therefore, time bucket is 1 month, quarter or a year based on the problem.

The Delivery Function requires

- The delivery constraints
  - Maximum amount of product quantity that can be delivered in one transaction
  - Type of loading
  - Timing of loading, truck availability
  - Transportation Lead Time
  - Process Successor-Predecessor Relations
  - Process Capacities
- Customer Orders are provided by an MRP system
- Available freight capacity
- Produced Quantity by production function
- Storage Locations and Location path, namely supply network structure.
- Available finished products per storage location.
- Inventory Balance Constraints
  - Number of finished products that is transferred in and out from one storage location to another

Possible objectives to be satisfied by delivery function are minimization of demurrage and freight costs and maximization of customer satisfaction and resource utilization.

2.1.3. The Inventory Handling Function

The inventory handling is all about the storage of finished products. Warehouse and DCs are flexible resources that can be managed by short-term contracts easily. Inventory Handling mainly focuses on inventory accuracy, storage of finished products, quality and safety issues and management of third-party contracts.

Locations of warehouses, stacking opportunities, labor force capacity are the main drivers that influence the performance in the finished product storage. Inventory locations and network between the plants and inventory locations directly affect the inventory handling function costs. These costs can be accounted in the delivery function but since these costs are related with intra-company costs, we account these in the inventory handling function. Capacity of the warehouse can be managed by different alternatives of storage and stacking types and increasing the capacity of the warehouse by renting external warehouse using mid-term contracts. In order to manage these mid-term contracts, a company should have a decision support system that is linked with all the other functions described in this thesis. Today, most of the manufacturing enterprises use third party logistic companies in their warehouse operations. Management of these companies are done via mid-term contracts. Labor force capacity, equipments and business needs to be satisfied are all defined in these contracts. Therefore, all the related costs are defined in the contracts and they should be managed by a decision support system.

The Inventory Handling Function requires

- Handling and Storage Constraints per Storage Locations
  - Total Storage Area
  - Handling Resource Capacity
  - Labor Force Capacity
  - Dock Capacity
- Inventory Balance Constraints

  - Number of finished products that is transferred in and out from one storage location to another
- ➢ Storage Locations
  - Path defined between storage locations. A plant warehouse, dc or an external warehouse can be defined as a storage location and a path can defined between any of the storage location
  - Storage Location definitions
- ➢ Inventory on hand per Storage Location

Possible objectives to be satisfied by inventory function are minimization of labor force, storage, handling and intra-company transportation costs. Inventory handling function provides tactical level plan for the management of intra-company transportation, distribution of inventory etc.

2.1.4. Resource Function

Resource function represents the management of renewable resources of a company such as machinery, equipments, labors, warehouses, trucks etc. Each of these resources may have an aggregation between each other. Each resource may use other resource's capacity so and so forth. Therefore, resource function is one of the main drivers of supply network planning and capacity planning. Cost analysis of resource maintenance, implementation of new machinery, phase-in and phase-out periods, fine-tuning and calibration of resources according the processes are major factors affecting speed of production, namely the production volume. When the tactical level capacity-planning point of view is concerned, the most important parameters are the scrap ratios, production capacity, resource usages of the processes and resource costs. Others are mainly more technical issues and therefore they are out of scope of this thesis. In conclusion, we are going to focus on the aggregation of hierarchy between the resource groups, resource group usages, which is a decision variable, and resource capacities in this framework.

2.2. Sales and Marketing Function

Competition level increased in markets because of globalization, low trade barriers and new technologies in recent years. Multinational companies started to see the world as a “Single Market”. Customer oriented thinking has become popular because of the high competition levels. In order to be leader of this new single market, companies should compete with both local and global competitors. This requires robust systems and proactive management.

It is important to forecast market demand and planning marketing activities that may affect customer demand such as promotions. Unfortunately, it is hard to achieve exact market forecast. If the dependence on market forecasts can be reduced, manufacturing and logistics costs can be minimized; quality of customer service can be increased. In ideal case, when a product is consumed on the shelf, this information is transferred to the system and the supply chain function triggers an immediate response. Unfortunately, it is not the case in real life. Therefore, market forecasts or in other words demand management is crucial to increase the market share in the Single Market.

As in traditional approaches, focus of the Sales & Marketing function is the demand management. Demand management starts with making accurate forecasts. Market demand is affected by many factors. It is directly correlated with the macroeconomic and industry specific figures. We will not go details of making accurate forecasts but we assume that demand forecasts are provided considering following figures listed below

- *GDP per Capita*: It is an indicator of standard of leaving in a country. GDP is a proxy for standard of leaving and it is not a direct major of it.
- *Purchasing Power Parity*: It is used to compare standard of leaving between countries
- *GDP growth*: It is main measure of the economic growth and increase in wealth in a company.
- *Real GDP*
- *Exchange Rate*: It refers to the currency risk.
- *Political Risk (Systematical Risk)*: It is inherent to the entire market or entire market segment. In other words it is un-diversifiable risk or market risk

For every market, region or country using above countries a Region Index should be available to make decisions or scenario analysis. Please not that, this part is out of our scope. In addition to above figures, an ideal market forecast should take into account the figures such as Market Penetration, Market Sales Volume, Brand Recognition and Loyalty, Competition Level in the markets, Level of Entry Barrier, Threat of substitutes and historical sales data.

We think that all of the above figures have effect on the accuracy of the output of proposed decision support system. Since they are out of our scope, we will only include market penetration, market sales volume and historical sales data among the above figures. Please note that it is hard to quantify these figures and including those will increase the sensitivity of the model.

Up to this point, the related function in the model is defined as Market Forecast function whose output is an accurate market forecast. Customer Service uses this output. Together with the market forecast, the Customer Service needs customer-based data such as

- Type of the Customer
- Buying Volume and Capacity of the Customer
- Customer Details
- Terms of Trade
- Delivery Frequency
- Service Requirements
- Products Demanded
- Handling and Storage Constraints
- And Corporate Business Targets

The ultimate output of Customer Service is the *business opportunities set* which is the main output or an input for the decision making function together with the production possibilities set of the supply network system.

2.3. Cost Function

Each of these functions refer different part of the whole business in reality and consequently each part of these has its own cost structure based on their business structure. Decomposition of the costs is significant for the decision-making. Cost is one of the main measurements in all of the enterprises and most of the manufacturing companies are cost driven. Most often decision makers need to know cost impact of their decisions. By separating the cost as function from others, we aim to manage cost accounting policies. Cost of an end product can be decomposed into production costs, delivery costs, inventory handling costs and resource costs by using cost function structure. On the other hand, this cost function directly serves to the budget management. It will definitely help to budget making process by decomposing the cost structure in to different layer of the business as it is in activity based costing. It rather serves as a reporting mechanism to the decision maker.

2.3.1. Supply Network Cost Structure

The Cost Function requires production costs, resource costs, delivery costs and inventory handling costs in order to develop the supply network cost structure.

- **Production Cost**: Represents material cost of producing one unit of stock keeping unit or product group.
- **Resource Cost**: This figure stands for resource usage cost of producing one unit of stock keeping unit or product group. Resources can be labor, machinery, truck, forklift etc.
- **Delivery Cost:** This figure represents shipping one unit of material from a one storage location to another. This storage location can be a warehouse, customer location, distribution center or plant. Using scenario approach different delivery costs can be set for several transportation modes.
- **Inventory Holding Cost**: It is the cost of storing one unit of SKU in storage locations. Please not that cost of storing a finished product in the customers' storage locations is represented in the customer service's cost structure.

Cost function can be used for both reporting and budgeting functions. Hereby, we shall explain some of its features

- Decomposes the supply network costs into production, resource, delivery and inventory handling cost per product and product group
- Provides to fallow-up costs per storage location, supplier, and resource and helps to set the most inefficient part of the supply network in terms cost
- Contribution of each functions cost as percentage to the whole supply network cost
- Provides sensitivity analysis for the target cost margins

2.3.2. Sales and Marketing Cost Structure:

- **Additional Demand Cost:** This cost item refers marketing activities. Togerher with the supply network function, it can be used for the decisions regarding the marketing activities such as promotions. Mainly, it is the cost of increasing the demand one unit.
- **Switching Cost:** This figure is for the selection of customer set. In other words, it is one of the main determinants of the decision making along with the period end bonus and discounts provided to the customer and inventory cost
- **Inventory Holding Cost:** Especially in the FMCG sector, this figure has an important impact to the decision making. It is used basically in the vendor owned strategies.
- **Unsatisfied Demand Cost:** It is the cost of missed cases. It is an intangible cost and directly depends on the bias of the decision maker
- **Period End Bonus and Discount:** Every company provides special discounts or period end bonuses for their distributors. It is one of the main approaches in demand management. It is accounted as cost of customer and it is a tangible cost.

Above parameters constitute the sales and marketing cost function, which is an integral part of the Company Cost Structure. These are the main parameters for the decision making system described in this thesis. Priori are exogenous variables and we assume that all these figures were used in advance to define the sales and marketing cost-structure. These exogenous variables are also significant for the reporting purposes. The output of the model will be presented and assessed in terms of the exogenous variables.

Please note that, cost function does not have any decision variable. It will provide the decision priorities of the other functions. On the other hand, by defining appropriate constraints, decision variables and being consistent with the linear modeling concepts, one can use proposed decision support system to find the optimum cost structure.

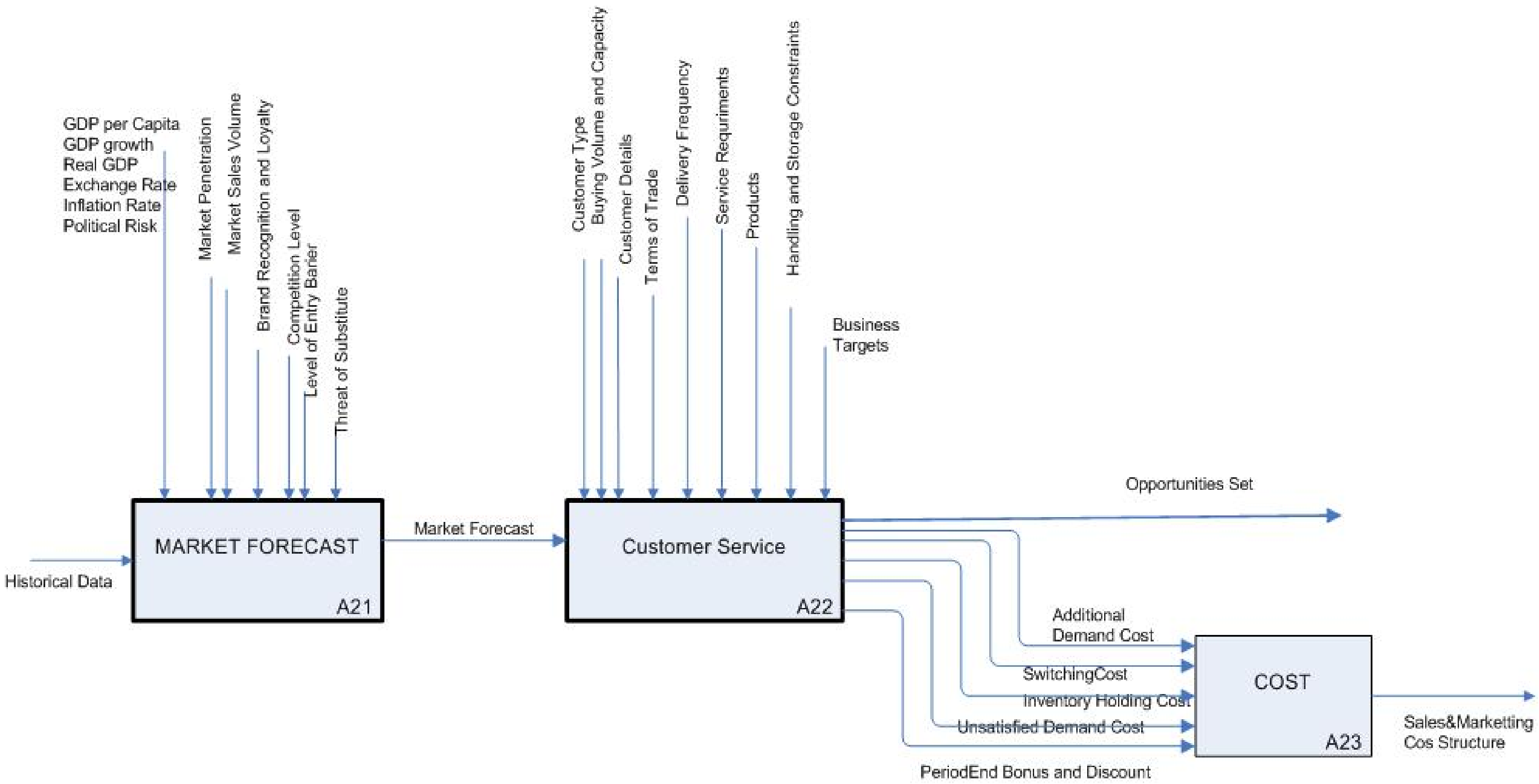


Figure 2.3. Framework of sales and marketing function

2.4. Strategic and Tactical Level Decision Making

In traditional decision making approaches, Sales & Marketing Function and Supply Network Function have a weak communication. Sales & Marketing Function targets to reply all the customer orders and Supply Network Function aims to satisfy all the demand and not cause any missed case. Therefore, a company that is managed in this approach may not operate on the efficient frontier.

Supply Network complexity is not digested by sales & marketing people and the corporate decision makers most of the time. Though the system is complex, decision makers should make related scenario and sensitivity analysis. This approach requires a well-designed decision support system that covers a wide functional area of the corporate.

When the Strategic Level Decisions are concerned, they are grouped in the literature as 8 different groups. These are listed below

- **Lean Logistics Strategies** are cost oriented. Supplying the same or comparable at a lower cost than the competitors in the market
- **Agile Logistics Strategies** are customer oriented and aim to increase product differentiation
- **Time Based Strategies** aim to decrease the efficient customer response time
- **Value Added Strategies** focuses on increased customer value
- **Growth Strategies** aim for economies of scale opportunities
- **High Productivity Strategies** aim full utilization of resources
- **Globalization strategies** which buy, store and move materials in a single, worldwide market

In other words, a decision-making process may have 8 different objectives to satisfy or combination of these objectives in different levels. Mixed integer programming and object oriented thinking that we used in this thesis provides the user combining different levels of objectives, sensitivity analysis and Pareto analysis. These objectives are the business targets that we define in our decision-making approach. We believe that decision makers should consider four levels of their system: Supply Network, Sales & Marketing, Cost Structure and the Business Targets. Large Systems may have more than one bottleneck in their system and localized decisions may not operate on the efficient frontier.

For instance, let us focus on the Float Glass Industry. Float glass manufacturing is a continuous process of manufacturing governed by complex relationships between products. Due to physical constraints, production can not be interrupted or cost of ceasing the production is high. Several products must be produced simultaneously by the nature of the process. Ratio of the products produced can be changed within some bonds and can not be fixed as in other co-production environments. Moreover, products are substitutable in the sense that demand for a lower quality of product can be satisfied by a higher quality product. A major problem within the float glass industry is that sales and marketing people, Sales and Marketing function, cannot digest the complexity of the production process. In turn, they cannot predict the results of the co-production structure. For example, receipt of an order for a significant number of Product A results in an increase in Production A. By the way, because of the co-production structure, production of Product A results in an increase in production of Product B and Product C as well. Since the increase in Product B and Product C production is not foreseen by the sales and marketing function, inventory level for the Product B and Product C pile up. By offering special promotions for this unplanned inventory pile up for the Product B and Product C causes a decrease in the Net Profit Margin.

The problem in the Float Glass Manufacturing explained can be solved by the decision support system described in this thesis. The problem can be managed by scenario-based demand planning considering production possibilities set versus opportunities set. Production possibilities set provide product substitution opportunities between different products. On the other hand, opportunities set provide sales prices of products, cross-sales opportunities and marketing goals. Finally, considering the both sets and the cost function, decision makers can analyze products that should be sold for the most profitable operation. Further, decision makers are able to plan even their missed cases, future customer opportunities, promotions and shipments.

2.5. ASSUMPTIONS

In this section, we have defined a general framework for our decision support system. This generic framework involves so many problems that we have experienced in different sectors including FMCG, electronics and glass manufacturing. Our object-oriented modeling structure provides a modular structure and enables an easy expending capability for the future. Consequently, phase-in of any of these modules will not be difficult and we have made below simplifications. Before going further into our proposed mathematical model, these assumptions are presented below.

- *Production Function:* Vendor managed inventory concept, quality aspects, safety stock and inventory record accuracy are not included in the mathematical model
- *Delivery Function:* Delivery constraints except the transportation lead-time and available freight capacity are not included
- *Inventory Handling Function:* Handling and Storage constraints per storage locations are not included in the mathematical model.
- *Sales and Marketing Function:* We will only include market penetration, market sales volume per customer and historical sales data. Please note that it is hard to quantify Brand Recognition and Loyalty, Competition Level in the markets, Level of Entry Barrier, Threat of Substitutes figures and including those will increase the sensitivity of the model.
- *Cost Function:* We used a linear cost function in our model which may only be valid in certain cases.

3. LITERATURE SURVEY

Relevant literature on supply network planning and decision support systems will be reviewed in this section. When the comprehensiveness of the related research area is considered, it will be inevitable to go over many research disciplines and papers.

In this section, we will present basic decision support systems, modeling tools related with the supply chain planning problems, some marketing literature including promotion planning and pricing.

Today, customers rule the markets and manufacturers are challenging to meet the customer demands for options, styles and features, quick order fulfillment, and fast delivery. In order to become success stories in the global market place, enterprises should learn how to improve management of their supply chain. When the supply chain is considered as a whole starting from the materials management, it includes many functionalities including procurement to marketing. Given the complexity of large systems and conflicting objectives of the each business unit such as marketing & sales, customer service, product supply, inbound & outbound logistics and procurement , it is substantial to have a decision support system covering various trade-offs and opportunities between these aspects [1]. Based on these concepts, Van Landeghem and Vanmaelle presented a framework that clarifies the roles of demand planning and supply chain planning. They provided a new paradigm for the tactical planning called robust planning. This new paradigm aimed at recognizing the uncertainty that is inherent in the supply chains [2].

Most of the literature discusses only the implications of one or two aspects of supply chain, for example, strategies, tools and techniques, but not in an entirety [9]. Decision Support Systems that combine several functional areas of an enterprise and provides what-if analysis are needed when the complexity of whole supply chain is considered

Studies encountered in the literature regarding with the sub-supply chain problems aim to minimize the cost or maximizing the profit of the business unit that is investigated with different methodologies or modeling experiences. These studies either focus on a single well-defined problem or try to develop a decision support system for multi-objective decision-making problems. Profit maximization problems are handled by using the duality property of the linear programming methodology and multi-objective decision making problems have multiple optimum solutions, namely efficient frontiers, by nature. All of the problems classified above involve uncertainty and complexity to some degree those are tried to be handled with different approaches such as stochastic programming, simulation, mixed integer programming, multi-objective programming [4], artificial intelligence, fuzzy reasoning and hierarchical programming.

Several studies can be found in the literature regarding each of the sub-problems of the supply chain planning. On the other hand, the extended version of the supply chain definition is known as the Value Chain [3]. The Value Chain of a firm defined by the Porter consists of Primary Activities and Supporting Activities. Objective of each activity is to offer a value which is greater that its costs, namely a profit margin.

Current decision support systems for supply network planning do not use the customer and market information sufficiently in a structured way. The customers and the market demand are considered as an exogenous effect. Therefore, supply chain planning frameworks has recently focused merely on the material flow disregarding the outbound logistics and it should be extended to have enough contribution of the customers and markets.

As it is mentioned above, there are several modeling practices for different kind of decision-making problems. Mainly these approaches can be grouped as fallowing

- *Stochastic Programming*: Real large-scale problems include uncertainty in the date and theoretically, it is reasonable to assume stochastic data. On the other hand, computational burdens and lack of modeling environments prevents these approaches to be practical,
- *Simulation:* It is widely used both in the literature and in real world applications,
- *Mixed Integer / Linear Programming:* When it is based on the reasonable assumptions and implemented with appropriate modeling environment, this

group becomes one of the best practices for solving large-scale decision-making problems,

- *Multi-Objective Decision-Making:* Multi-objective decision-making techniques are gaining popularity in most of the application areas.
- *Hierarchical Programming:* It is one of the basic tools to eliminate the implicit demand uncertainty and computational difficulties.
- Artificial Intelligence
- Fuzzy Reasoning
- *Hybrid Systems*: The lacks of appropriate integrated tools have led researchers to develop hybrid systems by combining above tools [5].

3.1. Stochastic Programming

In many modeling experiences, it is unreasonable to assume deterministic data. Honestly, this was a necessity for most of the real large-scale decision-making problems due to computational inadequacy in the past. LP modeling techniques are not suitable for modeling continuously distributed random variables. On the other hand, LP modeling languages are not satisfactory in representing stochastic modeling approach or scenario based linear programming approach. It is hard to parameterize variables in the large-scale linear programming models in the traditional LP modeling languages such as GAMS. Stochastic programming have been proposed and investigated since the 1950s [10],[11]. Advances in the computational area for the large-scale problems increase the focus of researchers on the stochastic characteristics of real large-scale problems. Few decision support systems for stochastic programming problems have been developed since Danztig [12], [13]. The lack of a suitable modeling management environment for the general multi-staging stochastic programming makes this modeling approach less usable than the linear programming based paradigms. E. Messina and G. Mitra have recognized the difficulties in the stochastic programming paradigm and discussed the development of a modeling and analysis environment that aims to develop a versatile tool that generates multi-period stochastic models and supports scenario approach. [14]

On the contrary of the current deterministic models recently used in the literature for the supply chain problems, Van Landeghem and Vanmaelle has shown the requirement of stochastic programming approaches for the supply network optimization.[2]

3.2. Simulation

Simulation is widely used in decision-making. The limitations of traditional simulation tools are many such as the difficulty associated with embedding complex decision logic in the hard-to-modify procedural code [15], a lack of constructs to deal with hierarchical model structures [16], and a difficulty in providing multiple levels of detail [17]. The IMSAT modeling approach addresses this problem by encapsulating the information and heuristics available to decision making functions as intelligent agents, entities that has an information processing capability, for the dynamic and hierarchical manufacturing environments. Nadoli and Biegel (1993) use intelligent agents to model the decision-making heuristics of systems such as material procurement, inventory control, production planning, maintenance, shop management and finance. The represented rule-based model is modular due to its object-oriented structure [18].

Supply chain planning problems involve some uncertainty and noisy information that affects decision-making process negatively. A decision support system that is designed for the supply network managers should handle this uncertainty at some level for the sake of the real-optimum solution. Scenario-based and simulation approaches are used most of the cases to remove the uncertainty for the decision makers. The best solution in real world depends heavily on forecasted market requirements [19].

3.3. Mixed-Integer Programming

Optimization technology such as linear or mixed integer programming with a hierarchical approach and simplifying assumptions is useful for solving complex supply chain planning problems as mentioned above. IBM T.J Watson Center has developed the supply chain simulator. The SCS help companies make strategic business decisions. The SCS provides modeling functions for seven different supply chain processes including customer, manufacturing, distribution, transportation, inventory planning, forecasting and supply planning. [20]

A decision support system is developed to solve an actual aggregate planning problem faced by a Portuguese firm that produces construction products by Da Silva et al.(2003). A multiple criteria mixed integer linear programming model is used to solve the APP. The model has been developed to optimize three performance criteria for a set of workforce, production, and inventory-related constraints. The performance criteria include profit, late orders, and the changes in the workforce level [21].

3.4. Multi-objective Decision Making

Decision making process may involve some level of uncertainty and have multi-objective structure. Many researches can be found in the literature regarding with the multi-objective decision-making. Pohekar and Ramachandran (2004) published a review of more than 90 published papers to analyze the applicability of various methods discussed in the literature. They observed that Analytical Hierarchy Process is the most popular technique fallowed by PROMETHEE and ELECTRE. On the other hand, DSS and multi-objective optimization techniques are not among the popular methods. [22]

The first aim of the any firm is to maximize its profits or in other words increase the shareholders value. The practice shows that the decisions are multi-criterion and depend not only on logistics and on industrial aspects, but also on economic and financial factors. Besides the cost minimization point of view, that is a general approach in the literature, Sámi Sboui and et. al. developed a profit maximization model which gathers the decisional (hierarchical, tactical and operational), economic , financial and budgetary aspects. Profit-maximization dynamic model allows highlighting the importance of financial aspects and could make evolve the trade of supplier-buyer to more rationality and reactivity according to the future profits [23].

3.5. Hierarchical Programming

A two-stage modeling framework with a chance programming approach handles demand uncertainty, customer demand satisfaction and inventory management issues. In addition to these, Gupta and Marinas also presented the effect of demand uncertainty to the whole supply chain including customer inventories. Presenting three type of demand regimes based on safety stock requirements, they developed different supply policies and inventory hedging suggestions for those different regimes. [24]

3.6. Hybrid Systems

The lacks of appropriate integrated tools have led researchers to develop hybrid systems by combining above tools [5].

LOP [25], a system of programming by logical objects, integrates logical programming, object-oriented approach, constraint programming and simulation; the Extool system [26] associates a production rules base with any object of a simulation model. Iassinovski et al studied a multi-period integrated model of optimization and simulations.

All of the above classifications are meaningful when their application of area, time of the study and purpose are considered. In this study, we will mainly focus on modeling the whole supply network, namely the value chain. Our model will touch every part of this network and enables the decision-maker to ask different kind of tactical and strategic questions about the system that is examined. Our model may be considered as a hybrid system since it involves an object oriented mixed-integer programming approach that enables decision-maker to ask several what-if questions by its scenario concept.

Up to know, we have mentioned several studies regarding with the supply chain planning. Our model involves similar concepts of the supply network such as production, logistics and inventory constraints; a cost minimization objective and demand uncertainty by nature. Nevertheless, before going further, we will provide some researches about promotion planning and marketing-manufacturing reconciliation since the value chain planning involves demand and customer, not the consumer in this study.

In previous, marketing managers often failed to recognize the multi-objective decision-making environment inside the companies. Decision makers in the marketing area should co-ordinate all their marketing activities such as promotion planning, advertising, and supply chain activities such as stock availability, vendor managed inventories, outbound logistics inventories in order to find the best product-mix, promotion-mix and advertising budgets. From the marketing point of view, the two elements of the marketing strategy are the advertising campaigns and the promotion plans. Sales promotions can be divided into several components [27].The use of sales-promotions have a short-term effect on consumer demand. On the other hand, advertising is a strategic tool that changes the brand recognition and value. In turn, effective advertising campaigns results in increased and stable demand in the end. According to Flanagan (1988) [28], sales promotion planning should be the part of the business planning. In other words, it should be the part of value chain planning, since it is a part of the whole value chain planning and directly effect on the brand value. In addition to promotion planning, pricing is another significant problem in the value chain planning. Pricing literature can be thought as the extension of promotion planning. Both of the pricing and the promotion planning requires accurate costs and their related analysis. Therefore, Decision Makers who have historically focus on sales and marketing share should focus more on the supply-network and the consumer reconciliation [29]. In today's competitive environment, it is the supply changes that are competing and not the companies.

The order promising system should have a link with manufacturing and distribution planning. In order to effectively promise orders, it is important to see their effects on manufacturing and distribution systems. There exist several dimensions of the order promising in the supply chains. Nevertheless, from the supplier point of view, the most interesting question is how a supplier firm should take part in negotiations between the players of the supply chain and how the supplying firm can quote and negotiate on prices, products, product features and due-dates [30]. Venkatadri et. al. (2005) has show how an optimization-based decision support system can be implemented to support these features. In their related research paper, a linear programming based order promising model is developed for demand management. Kawtummachai and Hop (2005) mention that optimization techniques have rarely used to order allocution. [31]

The construction of a decision support system for order management is outlined by C.Abid and et.al. [32]. A mixed-integer programming model has been developed to support sales department and form an interface between the market and the supply network. The objective of this study is to maximize the satisfaction of customers by an optimal arrangement of orders realization. A mixed-integer program was developed that takes into account on one side a set of manufacturing and logistics constraints associated to the mix of products, and on the other side clients' expectations and priorities. The order management tool controls the daily transaction between the customers and the company.

Recent studies show that companies that have sophisticated, agile and robust decision support systems for demand planning, increase their performance and customer service fulfillments [33],[34]. Moreover, manufacturing companies should have a tight link between marketing and manufacturing strategies. A decision support system that constructs this tight link will definitely ensure that right manufacturing capabilities are available to meet customer requirements. Furthermore, this link ensures that right supply-network components to be used effectively.

4. MATHEMATICAL MODEL

In this section, we are going to represent the mathematical model of our decision support system. Underlying framework and assumptions are defined above and related constraints and objectives of the mathematical model will be defined in this part.

4.1. Introduction

4.1.1. Supply Network Function

Supply Network Function is based on a number of key concepts. A part $p \in P$, models any item that can be purchased or produced. Parts enter the system through a process ($a \in A$) which may model either a supply process or production process. Eventually, output of a process is a part being introduced into the system and stored in an *inventory* ($i \in I$). A part stored in an inventory is removed from the inventory either to satisfy a customer order (which is called a *delivery* $s \in S$) or to be shipped to another inventory through a path ($h \in H$). Processes have related lead times, which indicate the time it may take to complete the process after it has started. We assume that all the parts generated during the process are entered into the output inventory at the completion period of the process. Capacity constraints such as machines, production facilities, labor, and suppliers are modeled as (renewable) *resource* groups. A resource group may be viewed as an aggregation of a group of resources. A single resource is also modeled as a resource group aggregating only itself. Resource groups may also have a hierarchy of aggregation. That is, a group can be defined as the aggregation of child resource groups, and a resource group can be a child of many resource groups. In this respect, only resource groups with no children in the hierarchy represent real capacity, whereas other resource groups are abstract groupings.

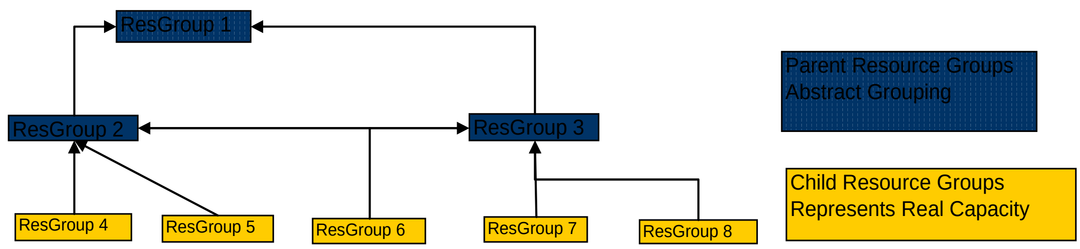
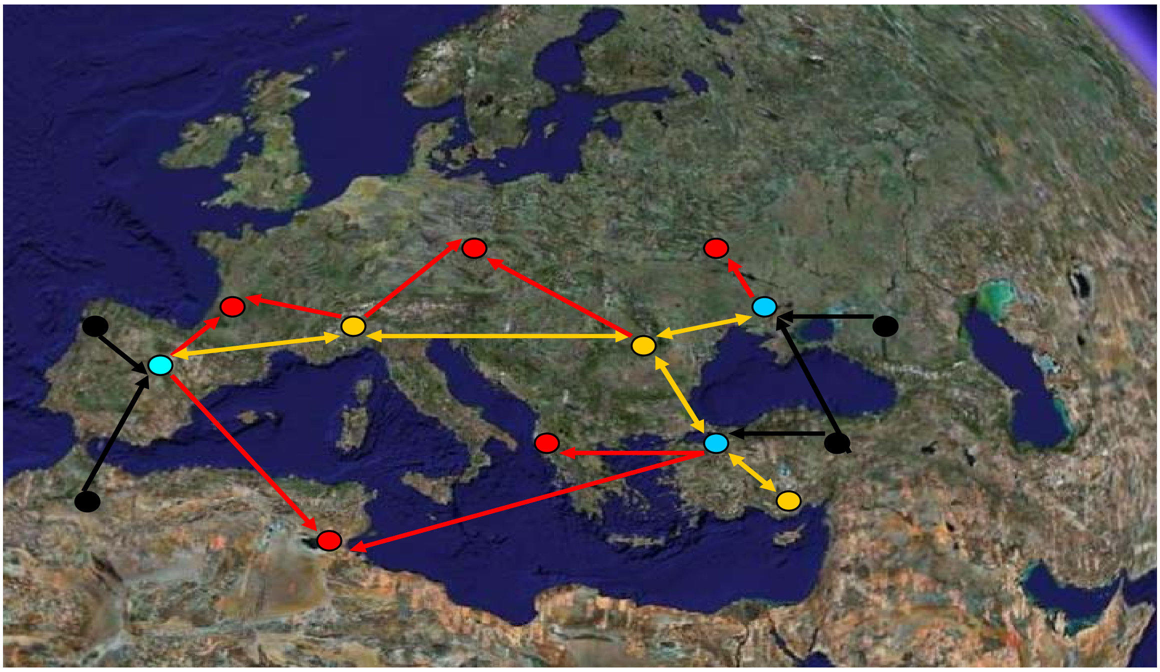


Figure 4.1. Resource group hierarchy

In Supply Network Function, *independent demand* $d \in ID$ models either a customer order, or sales forecast for a part. In either case, demand is manifestation of an independent request for a quantity of part to be delivered to a specific location (inventory) by a specific time. A production process may have a defined BOM structure, i.e., other parts (component items or materials) in specified quantities may need to be consumed during the process. This drives *dependent demand* $d \in DD$ for parts. We assume that component parts are to be delivered fully before the start of the process (completion time of the process - process lead-time). Processes may also consume capacity of resource groups. These are modeled as *resource group usages* $u \in U$, i.e., percentage of the resource usage at a particular period. A process may consume its resources in different volumes during the lead-time of the process



Plant — Refers to location of a production facility and inventory storage location. Finished products and some of the semi-finished products are produced, stored and shipped.

DC — Main inventory storage location, namely distribution centers.

Customer — Either a customer order or sales forecast for a part, namely independent demands

Supplier — Refers to location of a supplier. Purchased parts are transferred from the suppliers.

Part Delivery from Supplier

Delivery of Finished Products from Inventory Storage Locations, plant or DC , to Customer. Customer is either a district such as Central Europe or local customer such a distributor in a smaller region

Inter-Shipment deliveries between Inventory Storage Locations, so called paths

Figure 4.2. Basic supply chain structure

Relation between, demand, delivery, inventory and process can be viewed in Figure 4.2. Deliveries of independent demands can either be done on the same date as the period of the demand, or later (backorder, tardiness). In either case, the source for the delivery is an inventory. Each demand is expected to indicate a specific delivery inventory. Parts can be input into an inventory by either performing one of the processes (produce or purchase) that stores its output to that inventory, or by moving parts from other inventories. Dependent demands have the same delivery structure as independent demands and treated similarly. The major difference between a dependent and independent demand is that, delivering dependent demand after the demand date need not to be considered.

		1	2	3	4	5	6	7	8	9	10	11	12
Demand per Period	Customer 1	1000						1500					
	Customer 2				2000								
	Customer 3				1000								
Demand Satisfied in Period (Delivered)	Customer 1	500	500	0	0	0	0	100	100	100	200	500	500
	Customer 2				300	300	300	300	300	300	200		
	Customer 3				200	200	200	100	100	100	100		
Demand to be Satisfied (Delivered)	Customer 1	500	0	0	0	0	0	1400	1300	1200	1000	500	0
	Customer 2				1700	1400	1100	800	500	200	0		
	Customer 3				800	600	400	300	200	100	0		
Total Delivered in Period		500	500	0	500	500	500	500	500	500	500	500	500

Table 4.1. Delivery

In the example, which is represented in Figure 4.3, a small supply network structure is defined. Above example has 12 periods (t = 1, 2 … 12), one part (p = P1), 4 independent demands (d = 1, 2, 3, 4) from 3 different customers (c = Customer1, Customer2, Customer3). Assume there is one plant which produces product P1 and its monthly capacity is 500 items.

$q_1^D = 1000$ represents the demand for Product 1 in period 1 (Demand Per Period) and $S_1^D = 1,2,3,4,5,6,7,8,9,10,11,12$ are delivery alternatives for the demand (Demand Satisfaction Per Periods). It is clear that total amount of delivery should be equal to the quantity demanded in period 1. Demand in period 1 can be satisfied in 12 different periods based on the objective function such as

$$q_2^{S_1^D} = 500,\ q_1^{S_1^D} = 500 \text{ and } q_1^D = q_1^{S_1^D} + q_2^{S_1^D}$$

$$q_2^D = 2000 \text{ and } S_2^D = 4,5,6,7,8,9,10,11,12$$

$$q_3^D = 1000 \text{ and } S_3^D = 4,5,6,7,8,9,10,11,12$$

When the demands in period 4 are considered one of the satisfaction alternatives can be represented as

$$q_4^{S_2^D} = 300\,, q_5^{S_2^D} = 300\,, q_6^{S_2^D} = 300\,, q_7^{S_2^D} = 300\,, q_8^{S_2^D} = 300\,, q_9^{S_2^D} = 300\,, q_{10}^{S_2^D} = 300$$

and

$$q_4^{S_3^D} = 200\,, q_5^{S_3^D} = 200\,, q_6^{S_3^D} = 200\,, q_7^{S_3^D} = 100\,, q_8^{S_3^D} = 100\,, q_9^{S_3^D} = 100\,, q_{10}^{S_3^D} = 100$$

where total quantity demanded is equal to total demand satisfied

$$q_2^D = 2000 = q_4^{S_2^D} + q_5^{S_2^D} + q_6^{S_2^D} + q_7^{S_2^D} + q_8^{S_2^D} + q_9^{S_2^D} + q_{10}^{S_2^D}$$

$$q_3^D = 1000 = q_4^{S_3^D} + q_5^{S_3^D} + q_6^{S_3^D} + q_7^{S_3^D} + q_8^{S_3^D} + q_9^{S_3^D} + q_{10}^{S_3^D}$$

Total quantity produced and delivered in a period is equal to the production capacity of 500 items / month

$$q_4^{S_2^D} + q_4^{S_3^D} = 500$$

Highlighted cells are the deliveries that cannot be completed on time (tardiness).

Based on the above structure, we defined the constraints for the supply network functions. Main purpose of the Supply Network Function is to define a Production Possibilities Set (PS) which includes several product supply alternatives. Supply network constraints that formulize supply network function are explained further in section 5.7.

4.1.2. Sales and Marketing Function

Sales & Marketing Function aims to model marketing, sales and customer related concepts as mentioned in previous parts. A *market* $b \in B$ is the representation of a business unit in which a company operates. Each market has *product groups*. A *product group g* is the abstraction of products. Abstraction methodology of products may vary but in this context, it mainly refers to the grouping of products using the same renewable resources during the production. A *customer* $c \in C$ is an aggregation of demands. Customers may have a hierarchy of aggregation. A customer may have a parent customer and several children customers. Each market b may have several product groups as well as Customers. In this definition, a customer may refer to a geographical region such Central Europe, a country such as Turkey, a partner such as Carrefour, IKEA or a local distributor of the company.

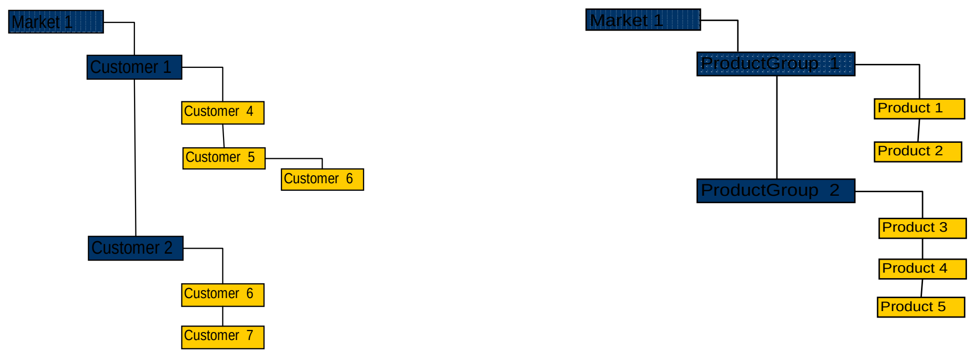


Figure 4.3. Customer hierarchy

Customers that have no child customer represent the quantity of demand per product that is a parameter for our mathematical model. As mentioned before both market and parent customers are abstract groupings.

Like the supply network function, a sales and marketing function is formulized based on the constraints, which are defined in section 5.8. The sales and marketing function defines feasible alternative solutions for investment, namely opportunities set.

4.1.3. Cost Function

Mathematical model underlying our decision support system is a cost minimization model. Therefore, cost parameters are important inputs to the model that shapes the final decision. Cost Function represents the whole cost structure of the value chain. Inventory

Costs, Process Costs, Resource Usage Costs, Transportation Costs are the connections of the cost function with the supply network function and the whole model. On the other hand, Customer costs connect the cost function with the sales and marketing function. Breakdown of the cost figures can be found in Section 4.2.3. We did not define any decision variable regarding with the cost figures and all the cost figures are embedded into the objective function as parameters. On top of, user can set any of this cost figures as a decision variable while not violating the consistency with the linear modeling concepts.

4.2. Structure

Time

T Period index

T Set of periods ($t = 0, 1, ..., |T|$)

T^+ Set of periods ($t = 1, 2, ..., |T|$)

4.2.1. Supply Network Function

Supply Network function is based on the supply network structure defined in section 4.1.1. In this section, mathematical declarations related with the parts of the supply network function including *Parts, Inventory, Processes, Demands, Deliveries, Paths, Resource Groups and Resource Usages.*

- *Parts* Parts model finished products, components (purchased or produced), or materials, and are input to the model.

  p Part index

  P Set of parts ($p \in P$)

- *Inventory* Parts have a number of inventories in which they can be stored as defined as input to the model. Each inventory of each part is given an index.

  I_p^P Set of inventories of part p

  i Inventory index

  I Set of inventories ($i \in I$)

  p_i^I Part of inventory i ($p_i^I \in P$)

- *Processes* A number of processes can be defined for each part. Each process index is one-to-one related to a particular part's particular process to be completed at a specific period.

  A_p^P Set of processes of part p

  a Process index

  A Set of processes ($a \in A$)

  A_s Set of supply process $a_s \in A_s \wedge A_s \subset A$

  i_a^A Output inventory of process a ($i_a^A \in I$)

  p_a^A Part of process a ($p_a^A \in P$)

  t_a^A Completion time of process a ($t_a^A \in T^+$)

- *Demands* Each delivery request (either based on an independent or dependent demand) for a part of a specific quantity at specific date on a specific inventory is called a demand and given a unique index. Demand is an input to the model.

  DD_a^A Set of dependent demands derived by process a

  $\forall d \in DD_a^A, t_d^D = \max(0, t_a^A - L_a^A)$

  d Demand index

  D Set of demands ($d \in D$)

  ID Set of independent demands ($ID \subset D$)

  DD Set of dependent demands ($DD \subset D$)

  p_d^D Part of demand d ($p_d^D \in P$)

  i_d^D Delivery inventory of demand d ($i_d^D \in I$)

  t_d^D Period of demand d ($t_d^D \in T$)

  a_d^D Process which derives d ($d \in DD$)

- *Deliveries* Each demand can be satisfied through a delivery from the designated inventory. A demand may have multiple deliveries depending on the time of delivery. Each specific delivery of a demand is given a unique index.

  S_d^D $\{s\text{: } d_s^S = d\}$ Set of all deliveries that can satisfy demand d

  For any $d \in ID$, there is one s with $t_s^S = t$ for each $\{t : t \geq t_d^D\}$

For any $d \in DD$, there is one s with $t_s^S = t_d^D$

s Delivery index

S Set of deliveries ($s \in S$)

t_s^S Period of delivery s ($t_s^S \in T$)

d_s^S the demand which is satisfied by delivery s ($d_s^S \in D$)

- *Paths* Parts are moved between inventories through defined paths. Path definitions are input to the model. Each path of each part is given a unique index.

  H_p^P Set of paths of part p

  h Path index

  H Set of paths ($h \in H$)

  if_h^H Starting inventory of path h

  it_h^H Ending inventory of path h

- *Resource group* Resource group hierarchy is an input to the model.

  r Resource group index

  R Set of resource groups ($r \in R$)

  P_r^R Set of parent resource groups of resource group ($r \in R$)

  C_r^R Set of child resource groups of resource group ($r \in R$)

- *Resource usages* A process may use capacity from a number of resource groups during the lifetime of the process (between its start and completion). Difference between the start and the completion of a process is called the lead-time of the process. Hence, a usage index is one-to-one related to a particular process' usage of a particular resource group at a specific period.

  U_a^A a Set of resource group usages during process a.

  There is one usage u where $t_u^U = t$ for each

  $\{t\text{: } \max(0,\ t_a^A - L_a^A) \leq t \leq t_a^A\}$

  u usage index

  U Set of usages ($u \in U$)

  a_u^U Process of usage u ($a_u^U \in A$)

  r_u^U Resource group of usage u ($r_u^U \in R$)

t_u^U Period of usage u

4.2.2. Sales and Marketing Function

This section gives mathematical declarations which are related with the sales and marketing functions. Sales and Marketing concepts which are handled in this thesis include *Business, Customer and Product Group.*

- *Business* Every product group can be classified under a business unit in which company operates. In line with this logic, Business model businesses in which company operates and they are input to the model.

  b Business Index

  B Set of Businesses ($b \in B$)

  PP_b^B Product group portfolio (set) of business b ($PP_b^B \subset P$)

- *Customer* Customer hierarchy is an input to the model.

  c Customer Index

  C Set of Customers ($c \in C$)

  PP_c^C Product group portfolio (set) of customer c ($PP_c^C \subset P$)

  C_b^B Customer portfolio of business b ($C_b^B \subset C$)

  C_c^C Set of child customers of customer ($c \in C$)

  C_g^G Set of customers that drive demand for product group ($g \in G$)

  P_c^C Set of parent customers of customer ($c \in C$)

  c_d^D Customer that drives demand d ($c_d^D \in C$)

  D_c^C Set of demands derived by customer c ($D_c^C \subset ID$)

  t_c^C Period of customer c ($t_c^C \in T$)

- *Product Group* Product Group hierarchy is an input to the model

  g Product group index

  G Set of product groups ($g \in G$)

  G_b^B Set of product groups belonging to market b ($G_b^B \subset G$)

  P_g^G Set of products belonging to product group g

D_g^G Set of demands belonging to product group g

4.2.3. Cost Function

- *Inventory costs*

  sc_{pit}^P Inventory storage cost per product in a specific storage location in a specific period

  hc_{pit}^P Inventory handling cost per product in a specific storage location in a specific period

- *Processes costs*

  pc_{at}^A Process cost of process a per product in a specific period $t \in T^+$

  mc_{at}^A Material unit cost in a specific period $t \in T^+$ where $a \in A_s$

- *Path costs*

  fc_{ph}^P Freight cost per product through a specific path in a specific period

- *Resource usage costs*

  rc_{rat}^R Regular usage cost of resource r by process a in specific period $t \in T^+$

  oc_{rat}^R Regular usage cost of resource r by process a in specific period $t \in T^+$

- *Customer costs*

  α_{cd}^C Discount cost for customer $c \in C$ per demand $d \in D_c^C$

  ε_{cd}^C Inventory holding cost for customer $c \in$ C per demand $d \in D_c^C$

  η_{cd}^C Period end bonus cost for customer $c \in C$ per demand $d \in D_c^C$

  ρ_{cd}^C Unsatisfied demand cost for customer $c \in C$ for demand $d \in D_c^C$

  χ_{cd}^C Additional demand cost for customer $c \in C$ for demand $d \in D_c^C$

4.3. Definitions

4.3.1. Supply Network Function

- *Inventory*

  S_{it}^{I} $\left\{ s : i_{d_s^S}^{D} = i, t_s^S = t \right\}$ Set of deliveries from inventory *i* at time *t*

  A_{it}^{I} $\left\{ a : i_a^A = i \right\}$ Set of processes feeding inventory *i* at time *t*

  HO_i^I $\left\{ h : it_h^H = i \right\}$ Set of paths with destination inventory *i*

  HI_i^I $\left\{ h : if_h^H = i \right\}$ Set of paths leaving inventory *i*

- *Processes*

  U_{ar}^{A} $\left\{ u : r_u^U = r \right\}$ Set of usages of resource group *r* during process *a*

- *Resource group*

  U_{rt}^{R} Set of usages of resource group *r* at period $t \in T^{+}$

4.4. Parameters

4.4.1. Supply Network Function

- *Inventory*

  Z_i^I Initial inventory stored in *i*

- *Processes*

  L_a^A Lead time of process *a*

- *Demands*

  q_d^D Quantity of demand *d* at a specific period ($d \in ID$)

  m_d^D BOM multiplier: Quantity of part p_d^D required for unit a_d^D ($d \in DD$)

- *Resource group*

  K_{rt}^{R} Independent capacity of resource group $r \in R$ at period $t \in T^{+}$

- *Resource usages*

  m_u^U Capacity of resource group r_u^U to be consumed per unit by process a_u^U

q_u^U Already completed percentage of the resource group consumption ($t_u^U = 0$)

4.4.2. Sales and Marketing Function

- *Customer*

  BC_c^C Buying capacity of customer $c \in C$ at a specific period $t_c^C \in T^+$

  DC_c^C Delivery capacity of customer $c \in C$ at a specific period $t_c^C \in T^+$

- *Product Group*

  MD_{gc}^G Market Sales Volume of Product Group $g \in G$ for customer c

  w_{gc}^G Market Share of Product group $g \in G$ for customer c

- *Business*

  w_{bc}^B Market Share of Business $b \in B$ for customer c

  MD_{bc}^B Market Sales Volume of Business $b \in B$ for customer c

4.5. Decision variables

4.5.1. Supply Network Function

- *Processes*

  q_a^A Quantity of process a at a specific period t_a^A

  q_u^U Percentage of regular resource usage at a specific period t_u^U ($t_u^U > 0$)

- *Inventories*

  q_{it}^I Quantity stored in inventory i at the end of period t ($t \in T$)

- *Demands*

  q_d^D Quantity of demand d ($d \in DD$) at a specific period t_d^D

- *Resource groups*

  $u_{r_1 r_2 t}^R$ Amount of capacity of group r_1 used by group $r_2 \in P_{r_1}^R$ at period $t \in T^+$.

- *Deliveries*

  q_s^S Quantity of delivery s at a specific period t_s^S

- Paths

  q_{ht}^{H} Quantity delivered over path *h* at period *t*

4.5.2. Sales and Marketing Function

- *Customer*

  ${}^{+}q_{d}^{D}$ Quantity of Additional Demand ($d \in ID$) for product p_{d}^{D} and customer c_{d}^{D} at a specific period t_{d}^{D}

  ${}^{-}q_{d}^{D}$ Quantity of Unsatisfied Demand ($d \in ID$) for product p_{d}^{D} and customer c_{d}^{D} at a specific period t_{d}^{D}

- *Product Group*

  q_{g}^{G} Quantity of Product Group demanded at a specific period t_{d}^{D}

- *Business*

  q_{b}^{B} Total Quantity of product supply for business *b* at a specific period t_{d}^{D}

4.6. Constraints

Equation (4.1) Resource usage

$$\sum_{u \in U_{ar}^{A}} q_{u}^{U} / m_{u}^{U} = q_{a}^{A}, \forall a \in A, \forall r \in R \tag{4.1}$$

All of the renewable resource should be fully utilized in a feasible plan. Based on the problem, this constraint can be released for under utilization of the renewable resources. In certain cases, usage of overcapacity may be needed which is presented in the above constraint

Equation (4.2) and Equation (4.3) Inventory balance

$$q_{it-1}^{I} + \sum_{a \in A_{it}^{I}} q_{a}^{A} - \sum_{s \in S_{it}^{I}} q_{s}^{S} + \sum_{h \in HI_{i}^{I}} q_{ht}^{H} - \sum_{h \in HO_{i}^{I}} q_{ht}^{H} = q_{it}^{I}, \forall i \in I, t \in T^{+} \tag{4.2}$$

$$z_{i}^{I} - \sum_{s \in S_{i0}^{I}} q_{s}^{S} = q_{i0}^{I}, \forall i \in I \tag{4.3}$$

Equation (4.2) represents the main inventory balance that is valid for each inventory location defined in the supply network. Please not that each of the storage location including warehouses, distribution centers, plants and customer locations defined under set of Inventory Locations. Breakdown of the terms in the Equation (4.2) can be found below

q_{it-1}^{I} Since the inventory balance equation is valid for every period and every storage location, an initial inventory level should exist. This term represents initial inventory level for all storage location in a period

$\sum_{a \in A_{it}^{I}} q_a^A$ This term is only valid in locations for plant. Since there is no production in locations other than a plant, this term will drop by definition

$\sum_{s \in S_{it}^{I}} q_s^S$ Defines the customer satisfaction in a period from inventory location such as warehouse, DC or production plant.

$\sum_{h \in HI_i^I} q_{ht}^H$ Defines the quantity of product that is delivered from one storage location to another. Transfer of stock keeping units from one location to another decrease the inventory level of sku's for the point of departure.

$\sum_{h \in HO_i^I} q_{ht}^H$ Defines the quantity of product that is delivered from one storage location to another. Transfer of stock keeping units from one location to another increase the inventory level of sku's for the point of arrival.

Any storage location can have some inventory for an sku defined by parameter Z_i^I. On the other hand, in terms of decision variable, q_{i0}^I represents the initial inventory and this should be reconciled with the input parameter Z_i^I

Equation (4.4) Resource group capacity

$$\sum_{u \in U_{rt}^{R}} q_u^U \le K_{rt}^R + \sum_{k \in C_r^R} u_{krt}^R - \sum_{k \in P_r^R} u_{rkt}^R, \forall r \in R, t \in T^+ \tag{4.4}$$

Proposed model involves resource group hierarchy as mentioned in part 4.1.1. Every resource should be defined as a resource group and each resource group may have either parent resource groups or child resource groups. If a resource a group has child resource groups, than capacities of these children should be added to the independent capacity of the resource. On the other hand, if a resource group has parents, than capacity used by the parents should be subtracted from the independent capacity of the resource.

Equation (4.5) BOM

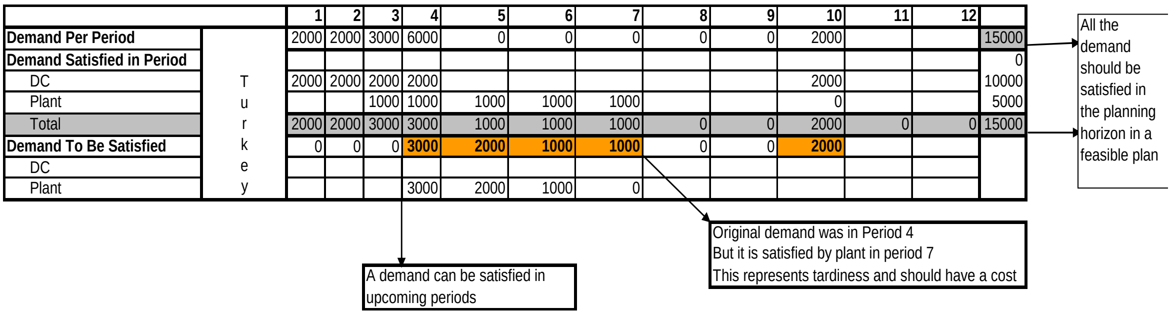
$$q_d^D = m_d^D q_{a_d^D}^A, \forall d \in DD \tag{4.5}$$

Dependent demands are derived based on Equation (4.5). If a process drives a dependent demand for a particular part, the quantity of the dependent demand is calculated from BOM multiplier of the finished product and the quantity of finished product produced, namely back flushing.

Equation (4.6) Demand - delivery

$$\sum_{s \in S_d^D} q_s^S = q_d^D + {}^{+}q_d^D - {}^{-}q_d^D \quad \forall d \in D \tag{4.6}$$

Total quantity of deliveries that can satisfy a demand d, S_d^D, should be equal to the quantity that is demanded in a feasible plan. Putting it differently, ending inventory at inventory location, which is defined for each customer, at the end of each period should be equal to the demand requested for that period. This enables us to control whole inventory level in the supply network including inventory of the customers.



		1	2	3	4	5	6	7	8	9	10	11	12	
Demand Per Period		2000	2000	3000	6000	0	0	0	0	0	2000			15000
Demand Satisfied in Period														0
DC	T	2000	2000	2000	2000						2000			10000
Plant	u			1000	1000	1000	1000	1000			0			5000
Total	r	2000	2000	3000	3000	1000	1000	1000	0	0	2000	0	0	15000
Demand To Be Satisfied	k	0	0	0	3000	2000	1000	1000	0	0	2000			
DC	e													
Plant	y				3000	2000	1000	0						

Figure 4.4. Demand satisfaction

We have defined the decision variables additional demand and unsatisfied demand for strategic marketing management. In case of under utilization of the total production capacity, additional demand provides the decision maker to come-up with a solution for his / her marketing plans per customer, period and product. On the contrary, in case of full utilization, decision maker is able to decide which demand to back-order per customer, period and product. Please note that, this decision requires a well-defined cost structure, which will be described in the next section.

Equation (4.7) Customer Buying Capacity

$$\sum_{d \in D_c^C} \sum_{s \in S_d^D} q_s^S \leq BC_c^C \quad \forall c \in C \quad where\ t_c^{\ C} = t_s^{\ S} \tag{4.7}$$

Every customer has a buying capacity. This capacity may be the storage capacity of the customer, its internal growth strategy or financial aspects. Therefore, total number of demand satisfied in a given period should bounded by the customer buying capacity. Please note that, in the supply network function we have modeled inventory for the entire supply network and aimed to minimize inventory levels through out the entire supply network. This equation is in line with our previous constraints. In addition to that, we assume that, demand forecasts are in line with the buying capacity of the customer and therefore unsatisfied demand variable is not added.

Equation (4.8) for each product group g

$$q_g^G = \sum_{d \in D_g^G} \sum_{s \in S_d^D} q_s^S , \quad g \in G \tag{4.8}$$

Strategic planning needs based on marketing decisions modeled in the decision support system. In most of the real applications, market forecasts are available on the product group level. Decision Makers should decide the optimum product-mix to satisfy the product group forecasted demand by considering necessary marketing plans which are modeled by additional demand quantity and unsatisfied demand quantity.

Equation (4.9)

$$q_g^G \le \sum_{c \in C_g^G} w_{gc}^G * MD_{gc}^G + \sum_{d \in D_g^G} ({}^{+}q_d^D + {}^{-}q_d^D), \quad \forall g \in G \tag{4.9}$$

Market Volumes and market penetration for different products are defined by different market researches and chief executive has his/her own perceptions about the market volumes. On top of, chief executives need a scenario-based, sophisticated but user-friendly tool to test, simulate or verify their perceptions. On the other hand, demands are estimated by sales and marketing departments of the companies based on the historical sales data, past experiences, price elasticity of demand etc. Please note that together with the Equation (4.6), Equation (4.9) has vital importance for this high-level decision-making. Lower level managers may not foresee privileges, confidential initiatives and investments. Therefore, the difference between the Estimated Market Volume, MD_{gc}^G, and forecasted demand , q_d^D, is filled with additional demand plus unsatisfied demand. This means that chief executives can give a direction to the organization by changing the target market penetration w_{gc}^G and estimated market volume MD_{gc}^G. On top of, when the market volumes of each customer are well defined, the proposed decision support system is expected to provide the related efficient frontier via supply network and sales & marketing functions.

Equation (4.10)

$$q_b^B = \sum_{g \in PP_b^B} q_g^G \quad \forall b \in B \tag{4.10}$$

The total business is divided into sub-businesses in most of the real applications. Each of the sub-businesses is defined as Business *b* in this thesis. Products that are included in this aggregation define total number of product supplied for a specific business unit.

Equation (4.11)

$$q_b^B \leq \sum_{c \in C_b^B} w_{bc}^B * MD_{bc}^B + \sum_{g \in G_b^B} \sum_{d \in D_g^G} ({}^{+}q_d^D + {}^{-}q_d^D) \quad \forall b \in B \tag{4.11}$$

Same discussion that was explained in Equation (4.9) is also valid for this equation. This equation is also a significant constraint for our decision support system. Please note that, we propose a decision support system in this context and do not aim to find the optimum or theoretically the best solution for the consumer driven supply network. High-Level decision maker should be able to touch the model and define it based on his / her needs. Therefore, w_{bc}^B and MD_{bc}^B define the target values for market penetration and Market volume respectively. Again, the discrepancy between target values and the estimated values filled with the additional demand and unsatisfied demand variables to provide the decision-maker direct the organizations long-term strategic plans.

Equation (4.12) Negativity constraints define all of decision variables as nonnegative continuous variables

$$q_a^A, q_u^U, q_{it}^I, q_d^D, u_{r_1 r_2 t}^R, q_s^S, q_{ht}^H, {}^{+}q_d^D, {}^{-}q_d^D, q_g^G, q_b^B \geq 0 \tag{4.12}$$

4.7. Productions Possibilities Set - *PS*

Supply network function defines the productions possibilities set, namely the feasible region. Product-mix alternatives based on the supply network constraints belong to production possibilities set**,** *PS***.** A standard supply network problem may have infinite number of solutions for the below constraint set. In our approach, we do not find the optimum product-mix, efficient frontier, for the value chain only considering supply network constraints and objectives. Polyhedron which is defined by Equations (4.1), (4.2), (4.3), (4.4), and (4.5) are called the Production Possibilities Set.

4.8. Opportunities Set - *CS*

Sales and Marketing constraints formulize the sales and marketing function. As defined in the previous section, using this function we try to model sales and marketing strategies of the company decision-making process. In other words, it defines a polyhedron on the space of decision variables regarding with the customers, global business units and product groups.

Equations (4.6), (4.7), (4.8), (4.9), (4.10), (4.11), and (4.12) define the opportunities set, CS.

Three major categories such as Product Groups, Global Business Units and customers are defined for decision making in this thesis. If a decision space is drawn as in the below figure, these three categories define a decision cube. When in the customer-based decision-making, product groups and global business units that the customer operates are considered which corresponds to plane in the three-dimensional decision space. Contrarily, the decision-maker may only focus on product-groups. In this case, aggregation will be on the product group level and correlation between the product groups plane are omitted. Finally, if the global business unit is chosen as an aggregation same problem will reply.

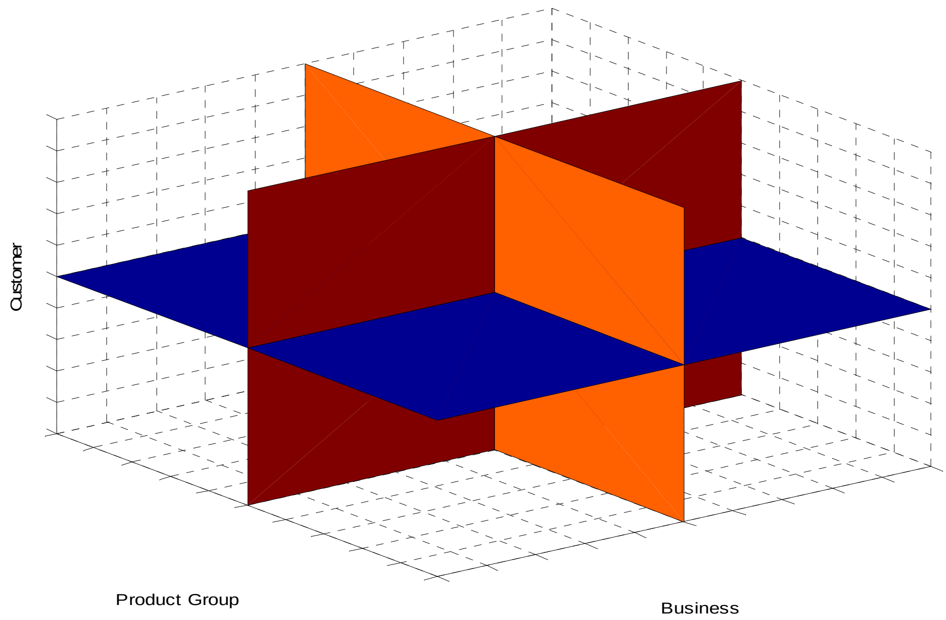


Figure 4.5. Decision space

The decision maker defines components of the objective function. Our decision support system aims to provide a sophisticated but user-friendly system for the decision makers. Thence, objective function should be multi-objective and flexible enough to satisfy decision makers' needs. Decision-Maker can choose any of the objective below and construct his/her own objective function.

Objective I: Minimizing inventory handling and storage costs .It is the summation over all inventory locations and periods (Equation (4.13))

$$\sum_{t \in T^+} \sum_{i \in I} q_{it}^I * (sc_{p_i^I it}^P + hc_{p_i^I it}^P) \tag{4.13}$$

Objective II: Minimizing freight costs. Since freight cost is defined per unit product through a specific path in a given period, it is the summation over all of the three indices

$$\sum_{p \in P} \sum_{t \in T^+} \sum_{h \in H_p^P} q_{ht}^H * fc_{pht}^P \tag{4.14}$$

Objective III: Minimization of total production costs is given by the third term of the objective function. As mentioned in previous chapters, process definition involves both processes within the plant and supply processes. Cost structure of these two concepts is little bit differentiated for the sake of the decision support system. Supply process involves the costs of material unit cost, mc_{at}^{A} and it represents the unit price of a specific part and most probably it has the biggest impact on the decision.

$$\sum_{t\in T^{+}}\sum_{a\in A} q_{a}^{A} * pc_{p_{a}^{A}at}^{P} + \sum_{a\in A_{s}}\sum_{t\in T^{+}} q_{a}^{A} * mc_{at}^{A} \tag{4.15}$$

Objective IV: Minimization of total Resource Costs is given by the fourth term of the objective function.

$$\sum_{r\in R}\sum_{t\in T^{+}}\sum_{u\in U_{rt}^{R}} m_{u}^{U} q_{a_{u}^{U}}^{A} * rc_{ra_{u}^{U}t}^{R} \tag{4.16}$$

Objective V: Minimization of sales and marketing costs term is rather complicated than the others. It involves different dimensions and some assumptions.

a. Equation (4.17): This term is based on the direct sales costs. We assume that discount per order, inventory holding cost by customer per product and period end bonus costs are the decided during sales negotiations. Moreover, they are included in the memorandum of agreement between the customer and company. Therefore, we define above costs per demand order. Discount per order, α_{cd}^{C} , and period end bonus , η_{cd}^{C} , are the costs that the supplier company want to reduce. On the contrary, we assume that inventory handling cost, ε_{cd}^{C} , is profit account for the supplier.

$$\sum_{c\in C}\sum_{d\in D_{c}^{C}} ((\alpha_{cd}^{C} - \varepsilon_{cd}^{C} + \eta_{cd}^{C}) * \sum_{s\in S_{d}^{D}} q_{s}^{S} \tag{4.17}$$

b. Equation (4.18) represents the direct marketing costs. We assume that these costs are activity based. Therefore, we have defined these costs per demand order, which involves customer, product, market, and period information.

$$\sum_{c \in C} \sum_{d \in D_c^C} {}^{+}q_d^D * \chi_{cd}^C + {}^{-}q_d^D * \rho_{cd}^C \quad (4.18)$$

A decision maker may not have the need to use all of the cost figures. In the below section, we defined an interface which enables user to decide a set of cost figures based on his / her needs.

When the cost structure of the proposed model is properly defined and effectively used, this approach involves the Activity Based Costing (ABC) by itself.

Finally, Equations (4.13) to (4.18) aim to operate on the efficient frontier by considering both supply network costs, sales and marketing costs. Priority of the selection criteria depends on the business and weight of costs. No prioritization is set for the costs.

Please note that based on the needs, decision maker can alter both the objective function and the constraint set. He/She can include all of the conflicting objectives or get some portion of it by using the interface that we will describe in the next section. Briefly, we can provide the fallowing decision-making algorithm for representation.

For all Scenarios **Do**

'You can create as many scenarios as you want based on your problem for both of the supply network function and sales and marketing function'

For all Functions **Do**

If Function = "Supply Network Function"

Then 'Actually this part defines production possibilities set, PS'

Set *Inventory, Processes, Demands, Delivery, Path, Resource usages, Resource group* **Parameters**

Else if: Function = "Sales and Marketing Function**"**

'Define Opportunities Set, CS'

Set *Customer, Product Group, Business* **Parameters**

Else: Choose associated costs using interface

'Includes 5 objective sets defined above'

'Define your selection criteria for the efficient frontier. If the cost term multiple set to be one, then its effect will be disregarded'

End if

End if

End For

Solve Model

End For

Compare Results of each scenario

Please note that cost function has no decision variable in the current set-up and it is embedded into the objective. On the other, decision-maker can easily set any of the cost function figure as a decision variable rather than a given parameter.

5. IMPLEMENTATION

The proposed decision support system for consumer driven supply networks has been developed and implemented in ICRON $_2$ modeling environment. ICRON $_{2,}$ which is an object oriented modeling environment, has an integrated visual algorithm component that makes model development progress easier for every kind of practices. By its drag and drop technology, nodes are connected to each other as in flow charts to construct algorithms for any kind of decision-making problem. A node represents a specialized function which returns a predefined output and it is designed to make life easy for modelers who have limited computes science background.

ICRON$_2$ has a modular structure is leveraged by XML and C++. The environment enables development of hybrid and sophisticated decision support systems by combining distributed computing, mathematical programming, heuristic approach, high integration capability with databases such as SAP and Oracle , MS OFFICE components and web-service support.

The key issues regarding mathematical programming in ICRON$_2$ are [40]

- Object oriented data modeling in ICRON$_2$ represents data in objects rather than rational databases, vector or matrix forms which is the main difference of ICRON$_2$ from other modeling environments such as GAMS, LINGO, AMPL
- With its modular and flexible environment, ICRON$_2$ differs from other modeling tools. It provides users to embed the mathematical model in an executable algorithm environment, which collaborates with several other applications and databases.
- Modeling structure and data structure is separated from each other in ICRON$_2$. Scenario based approach, quick implementation and reapplication becomes available with this property. After constructing a standard infrastructure for a generic problem such as capacity planning, a user can expend and reapply the approach for different problems. Mathematical model is developed independent of decision variables and parameters. Decision variables can be

designated at any stage before solution which provides flexibility and capability for decision support systems. Modeler can use any part of a large-scale mathematical model using this property.

5.1. Object Oriented Model

Designing and Planning of a supply network is complex by its nature. Many instances, complicated and cryptic relations between the instances and concepts may easily increase the complexity of the problem and require sophisticated solution techniques. Object Orientation is a better abstraction of the Real World among the other abstraction techniques. In theory, this means if the problem changes, the solution should be easier to modify as the mapping between the problem and solution is easier. In large systems, if the system is not designed properly small changes in one instance or dimension may affect the whole system. Object Oriented Approach prevents these problems and provides systems that are more robust.

Classes in the object-oriented approach define dimensions of the network. Two things can characterize objects in the real world: each real world object has data and behavior. Objects are instances of classes and classes are templates for objects. A class describes what attributes and relations will exist for all instances of the class. Another important point is the behavior of the whole system. Objects and classes are not solely sufficient to describe the behavior of the system. Classes are low-level entities and do not really describe what the system can do as o whole. Therefore, a conceptual model (the class diagram approach of UML) that is represented in this thesis is presented in the below figures.

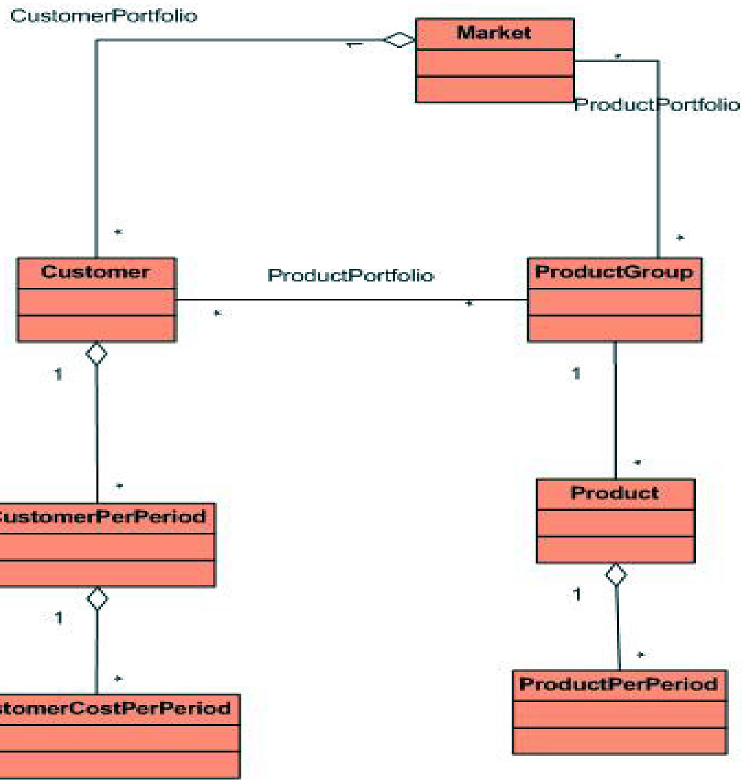


Figure 5.1. Object model of sales and marketing function

- **Market** represents a global business unit in which company operates. It is an aggregation of product groups based on the marketing strategy. It has relations to customers and product groups within the global business unit.
- **Market per period** involves information regarding with a specific business in a specific period. The class has the attribute of Market Sales Volume and relation to its market class
- **Customer** is the aggregation of demand in terms of geographical region, country, company partner or a distributor. It has a parent-child relationship between its objects. Each customer object has a relation to its parent and child customers, demands, product groups, costs and the market.
- **Customer per Period** contains information about a customer in a given period. It has relations with its all product groups, parent and child customers and demands for the specific period.
- **Customer Cost** contains relations for a specific customer.
- **Customer Cost per Period** involves information about the cost structure of a specific customer in a given period. It has the attributes of switching *cost*,

discount, period end bonus, additional demand cost, unsatisfied demand cost and inventory holding cost.

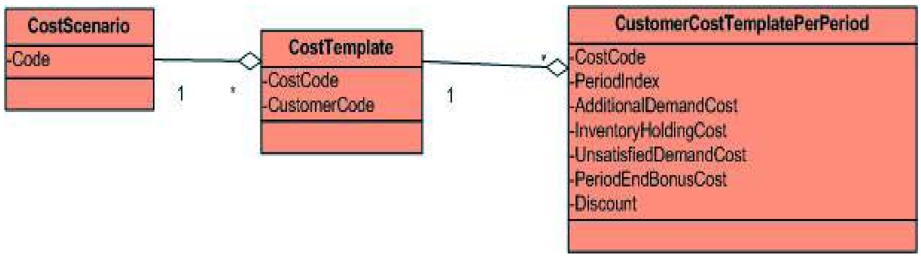


Figure 5.2. Object model of sales and marketing cost function

- **Product Group** is the abstraction of products. Abstraction methodology of products may vary but in this context, it mainly refers to the grouping of products using the same renewable resources during the production. A product group object has relations to customer, market and product objects. Every product group object has list of product group per period object that defines periodic information.
- **Product Group per Period** involves information regarding with a specific product group in a specific period and it has attribute of quantity demanded. Every product group per period object has relation to its own product group object.
- **Part** represents any item that can be purchased or produced. A part object has relations to its own part per period, inventory, path and process objects.
- **Part per Period** involves information regarding with a specific product in a specific period and a part per period object has relation to its own part object.
- **Part Process** represents either a supply process or production process. Parts enter the system through a part process. A part process object has relations to its part process per period objects and part object.

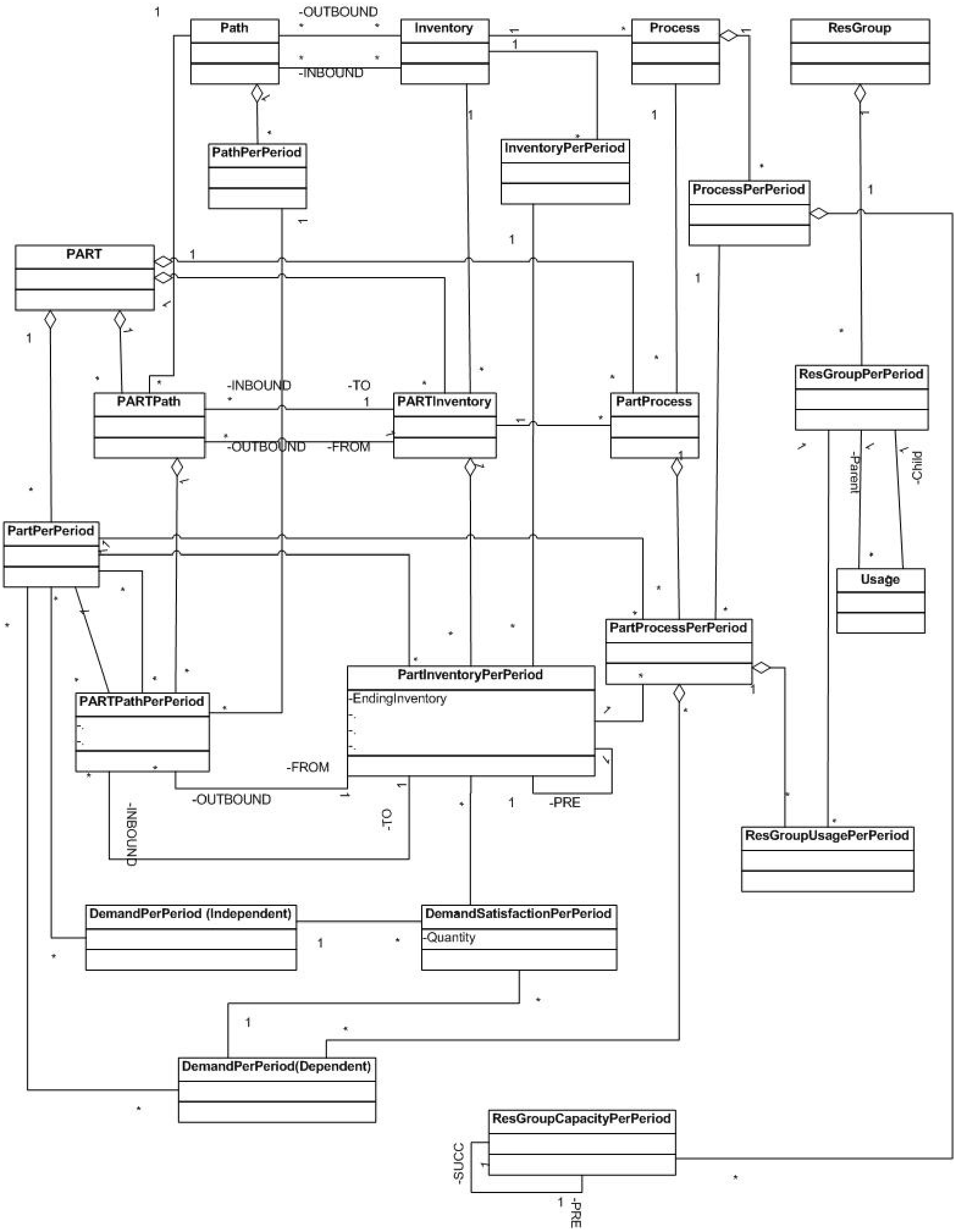


Figure 5.3. Object model of supply network function

- **Part Process per Period** involves information regarding with a specific process of a specific part in a given period. It has *quantity* attribute that holds the quantity produced for a part in a period by the process and it has relations to part process, part inventory per period, demand satisfaction per period, dependent demand per period, resource group usage per period, par process cost per period objects.

- **Part Process Cost** contains relations and information for a specific part process object. It defines the storage location, marker code, process code
- **Part Process Cost per Period** involves information about the cost structure of a specific part process in a given period. It has an attribute of unit process cost and a relation to own part process and part process per period objects.
- **Part Inventory** involves initial inventory of a specific part in a specific inventory location. A part is stored in a inventory location and that inventory location is represented by part inventory. It has relations to part and part inventory per period objects.
- **Part Inventory per Period** holds ending inventory information for a part inventory object in a specific period. It has relations to demand satisfaction per periods, inbound part per periods, outbound part per periods, part process per periods, and part periods. A part inventory per Period object should have relation to its priori per period object for inventory balance.
- **Part Inventory Cost** contains relations and cost information for a specific part inventory object. It holds information about the storage location, marker code, part code.
- **Part Inventory Cost per Period** holds storage cost and inventory handling cost for a specific part in a specific storage location in a given period. It has relations to part inventory and part inventory per period objects.
- **Part Path** represents a path definition, which a part is delivered to a part inventory location or customer. It has the attributes of from location code, to location code, path code and relations to part path per period objects.
- **Part Path per Period** holds information of transferred quantity through a part path and lead-time of the transportation. It has relations of inbound paths, outbound paths and part path objects.
- **Part Path Cost** contains relations and cost information for a specific part path object. It holds information about the part path definitions and relation to part path object.

- **Part Path Cost per Period** involves cost information regarding with a part path in a given period. It has a freight cost per unit attribute together with relations to part path cost and part path per period objects.
- **Resource Group** involves information regarding with the renewable resources such as machinery, equipment, labor and suppliers. It may be an aggregation of resource groups. It has a parent-child hierarchy and it has the relations to parent resource groups, child resource groups and resource group per periods.
- **Resource Group per Period** holds relation of a resource group with other per periods objects for every periods. It has relations of child resource group per period relations, parent resource group per period relations, resource group usage per period, resource group capacity per period and resource group itself.
- **Resource Group Capacity per Period** holds the capacity information of a resource group for a specific period and it has a relation to resource group per period object.
- **Resource Group Usage per Period** represents the usage of a resource group by a specific process in a given period. It has the attribute of required capacity and resource code. It has relations to part process per period and resource group per period
- **Resource Group Cost** contains relations and information for a specific resource group object. It holds information about the part path definitions and relation to part path object.
- **Resource Group Cost per Period** involves cost information regarding with a resource group in a given period. It has a resource usage cost per unit attribute together with relations to resource group cost and resource group per period objects.
- **Independent Demand per Period** represents either a customer order or a sales order for a part and request for a quantity of part to be delivered to a specific location by a specific period. It has attributes of demand quantity, customer location and part code. It has relations to part and demand satisfaction per period objects.
- **Dependent Demand per Period** represents quantity, which is drived by a process, for specific part according BOM multiplier in a specific period. It has

an attribute of quantity and relations to part, part requirement and part process per period objects.

- **Demand Satisfaction per Period** represents delivery of a part from a specific inventory location to a specific customer location in a given period. It has an attribute of quantity delivered and relations to part process per period and part inventory per period objects.

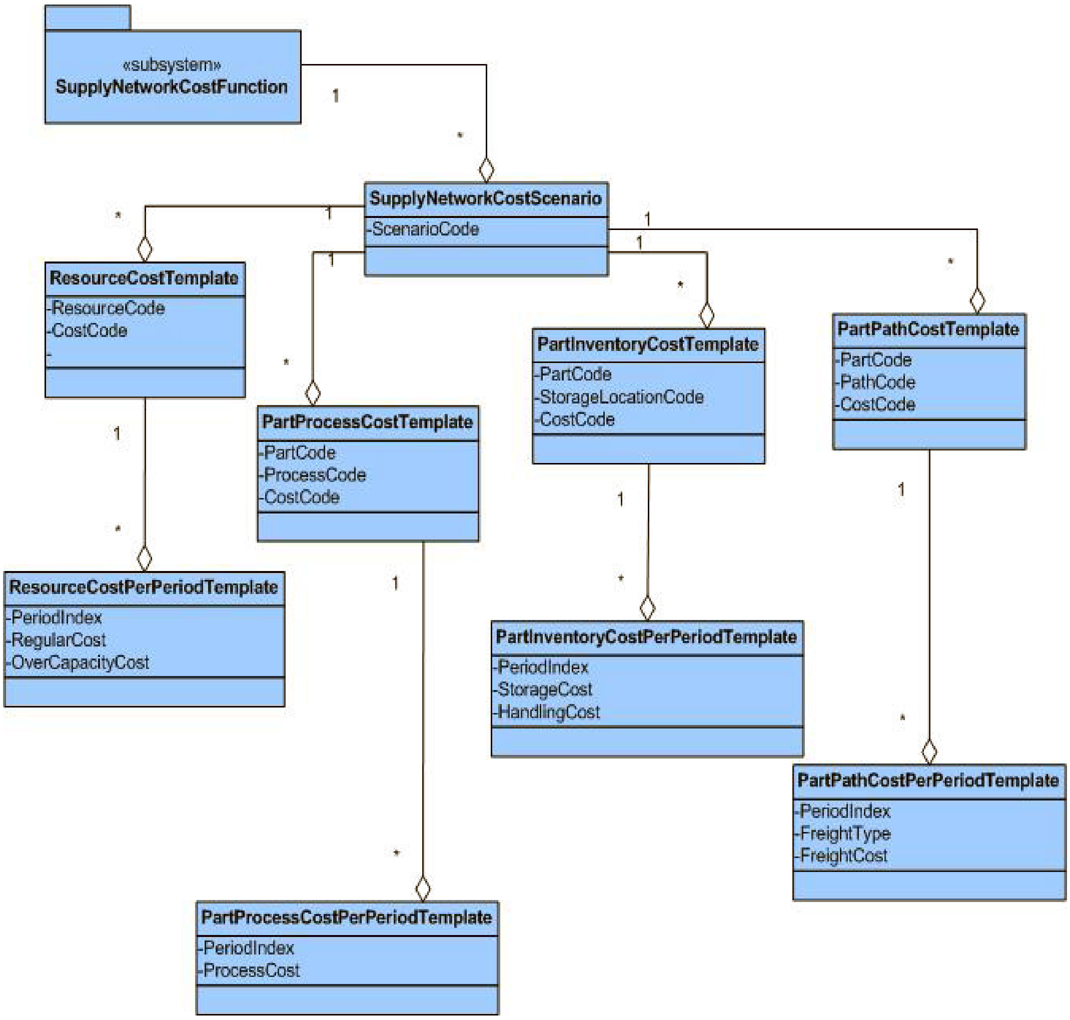


Figure 5.4. Object model of supply network cost function

5.2. Modeling Practice in ICRON$_2$

Figure 5.5 is a screen shot of algorithm in ICRON representing Marketing Constraint Equation (4.9). As mentioned above algorithm representation is similar to standard flow-chart representation. Each box is called a node in ICRON terminology and represents an algorithm. Starting from the top, the first node **Navigate List of Objects**, returns list of objects of a given class. In this case, navigate returns all of the market objects. The succeeding navigation node returns the customer objects of the each market, which is provided as input, by the previous navigation object. The third navigation node returns customer per period objects and the node **ListIterate** defines iteration on the customer per period object list. Since the marketing constraint will be valid on each demand per period of a single customer, a **Navigate** and a **ListIterate** node is used. Finally, the Constraint node creates the marketing constraint which is defined in Equation (4.9).

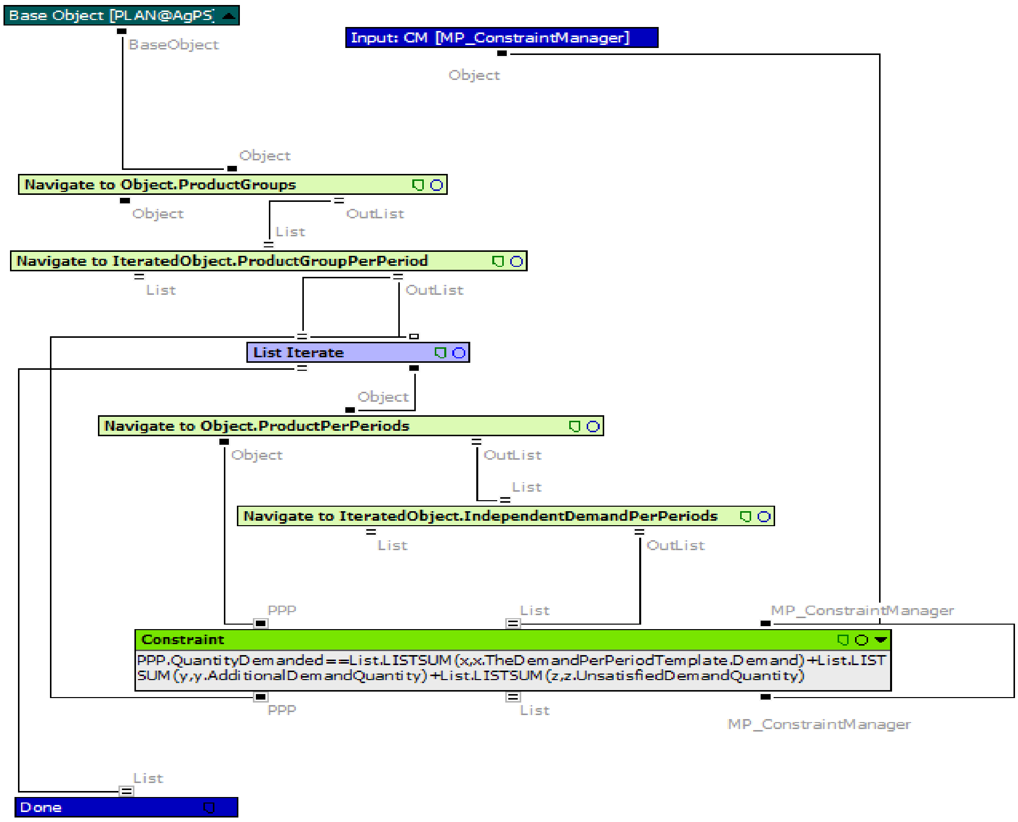


Figure 5.5. Equation 4.9 in $ICRON_2$

5.3. Interface of DSS in $ICRON_2$

From the experiences and literature, we observed that a well designed interface for decision support systems is important. In most of the cases, decision makers have little time or modeling experience. Decision environment and objectives may change. Therefore, we have defined an interface based objective function cost parameters, capacity parameters and initial inventory level for all categories. By selecting and deselecting the cost in the linear objective function, one can alter the dimension of the generic problem defined in this thesis. In the previous sections, we defined sub-functions of the consumer driven supply network, namely sales marketing, supply network and cost functions. Each of these main functions has sub-functions such as resource, production, delivery, customer service etc. Every decision maker was handled by a function in this thesis and modeled accordingly. On top of these, we have also defined different user interfaces, called a node in Icron, to support decision-making. Below, we are going to represent our decision nodes and how these nodes can be used to create Pareto efficient sets.

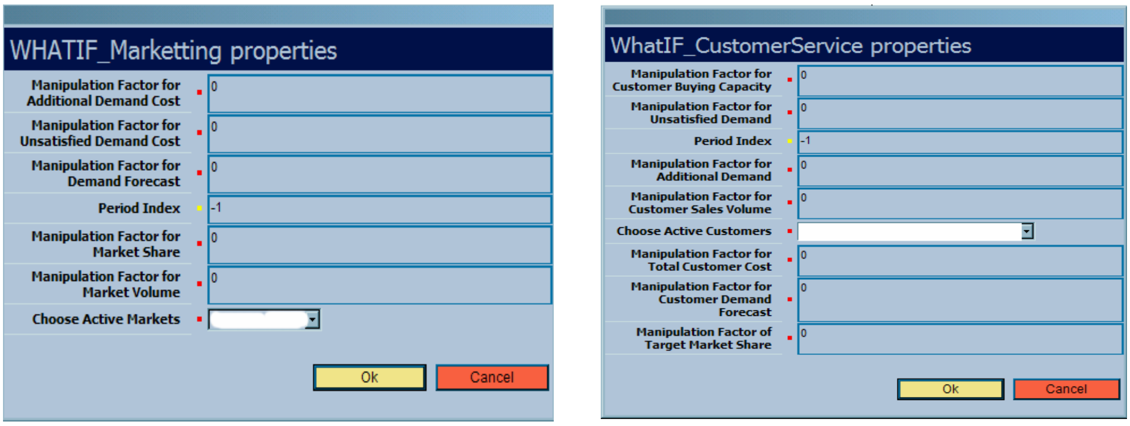


Figure 5.6. Decision Nodes for Sales and Marketing

Each node was designed to make what-if analysis for designing strategies. Each field in the above screen defines a manipulation factor for the related model parameter. On top of, minimum level of the manipulation factors was defined as -1 and no upper bound was defined. This abbreviation exists through out the all decision nodes. User can also make period based analysis by choosing the investigated period among the others. If period index is set to be -1, manipulation applies to all periods and objects.

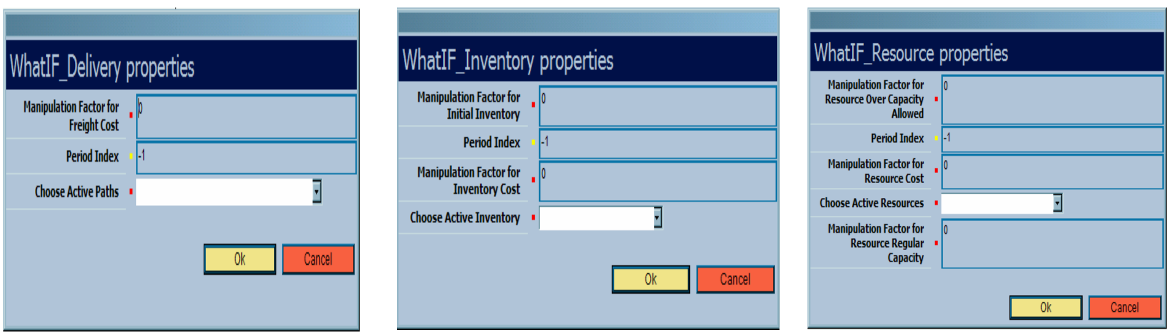


Figure 5.7. Decision Nodes for Supply Network

All of the above nodes involve parent-child relations between the alternatives such as defined in the above object model. Therefore, decision maker is able to make different type of what-if analysis for different groups of customers, products, resource groups, paths or inventory locations, if the supply network structure is designed accordingly. For instance, if the multiple for the additional cost is set as one, it applies down to all of the customers that belongs to that market. Same logic is also valid for other level of groupings.

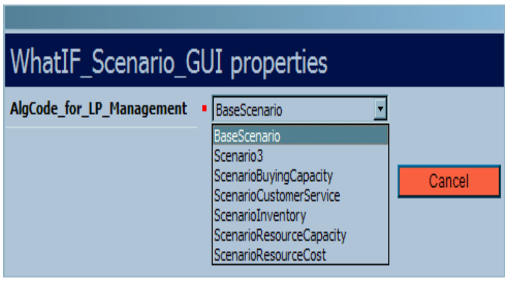


Figure 5.8. Scenario GUI Node

Above decision making nodes can be used to make several different types of scenarios, which can be selected before running the LP using the above node, Scenario_GUI. Current figure lists seven scenario variants for what-if analysis. The list includes a base scenario, five independent scenarios, and a composite scenario which is a combination of those. In the next section we are going to provide explanations for these scenarios and how we use the decision nodes to create these alternative solutions.

5.4. Sample Scenario

We designed a fictitious scenario for multinational company, which operates in FMCG business to test our Decision Support System and the proposed model. Briefly, our scenario has following properties

Property 1: Two Global Business Units, which are managed through out the world, namely the single market that was defined in the above chapters.

Property 2: We consider only three continents. Europe, Africa and Asia are the continents that we consider in the scenario. Europe region includes 27 countries while

Africa has 4 and Asia has 19 countries. In line with this, each country should be considered as a child customer and each continent, region, should be considered as a parent customer.

Property 3: Planning Horizon includes 12 periods where length of period is one month.

Property 4: Each and every child customer has projected market volumes, targeted market shares for each period and forecasted sales based on historical sales data.

Property 5: There exist 12 plants for both of the business scattered thorough out the three regions. Europe region has five Market B and four Market F plants; Asia region has four Market B and four Market F plants and rest of the plants locate in Africa region.

Property 6: Each plant has also both finished product inventory and resource materials inventory. Current scenario does not have any distribution centers.

Property 7: Each customer can be supplied from any of the plants. There is no trade constraints have been defined.

Property 8: Each plant is dedicated for a single business unit. Therefore, it can only produce the product groups or products that are dedicated to the business unit.

Property 9: Both Market F and Market B has a single product group defined. On top of, Market F has two products defined under product group PG_F and Market B has three different products alternatives defined under product group PG_B.

Property 10: Every Market F and Market B plant can produce all type of the products.

Property 11: 6 Raw materials have been defined where two of them are used in all of the products, 2 of them are dedicated to only two different products

The company has a target to grow in new markets such as Middle East and Africa. Therefore, new business, supply network and marketing plans should be revisited based on the company's vision. The untouched African and Middle East Markets offer many opportunities for different areas of the business. Current level of the Market Volume is not known especially in the Africa and the whole continent does only have eight new plants. On top of, these new candidate markets have many disadvantages such as deficient logistics capacity and customer service, inefficient supply network and long lead times. Therefore, the African market should be supported from other plants in Asia and Europe.

The company aims to increase its market share and total market volume by implementing right marketing and supply network strategies in both of its businesses.

Hence, promotion planning becomes very important to support these strategies and customer promotion premiums such as period end bonus and discount per product are arranged accordingly. Distribution of discount and inventory holding costs should be in line with the company strategies. Please note that, these cost parameters are *key decision parameters* of our decision support system that aims to reflect the decision maker's perception together with actual cost levels. Production capacity is diverted homogeneously through out the world. Our company which is studied in this case, is assumed to be a multinational that has high standards, technological capabilities, and improved production processes.

Even in this small case study, complexity of the problem is remarkable. Below, you can find some representing numbers of this complexity of the value chain

Total number of customers is fifty-three and there exist a parent-child relationship between the customers. These fifty-three customers 5 different cost figures for each period which contribute to a total of 3420 different cost figures. In addition to that, total of 1368 capacity figures, 684 market penetration and market volume data.

Fifty-three Inventory Locations that have 2067 cost parameters. Each inventory location refers to the total number of finished product inventory in a sub-region

We think that every supply chain network has inefficiency. There are always some untouched locations exist in a companies target markets. For instance, the company that is investigated in this thesis has only 5 production plants for the whole African market. Capacity problems in production and distribution, safety and environmental constraints, improperly managed marketing campaigns causes the total market volume to drop. On the other hand, every company is aware of this inefficiency and has perceptions about the possible value of the market volume. Marker Volume that is defined in this thesis refers to this perception. When it is properly define together with the market penetration, the whole model aims to suggest a feasible marketing, distribution and capacity plan for the entire value chain starting from supplier to consumer.

As mentioned above, the ultimate aim of this thesis is to provide a supporting tool for executives in order to analyze their strategic decisions. Each of the objective function can be easily included or excluded from the decision criteria during what-if analysis using the DSS Node Manager that we have designed in ICRON which were presented in the previous section.

6. RESULTS

We have defined eight different scenarios to present our proposed model. Manipulation factors for different parameters are presented in the below table. Each scenario was constructed using the above decision nodes. We have tried to generate an efficient frontier using the above decision nodes under defined fictitious case.

Table 6.1. List of Manipulation Factors

ScenarioCode	Reource Cost		Process Cost		Buying Capacity		Additional Demand Cost		Unsatisfied Demand Cost		Freight Cost		Inventory Cost	
	B	F	B	F	B	F	B	F	B	F	B	F	B	F
BaseScenario	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenario 8	-0.5	-0.5	0	0	0	0	0	0	3	3	0	0	0	0
Scenario 9	-0.5	-0.5	0	0	0	0	0	0	3.2	3.2	0	0	0	0
Scenario 10	-0.5	-0.5	0	0	0	0	-0.5	-0.5	3.6	3.6	0	0	0	0
Scenario 13	-0.5	-0.5	0	0	0	0	-0.5	-0.5	4	4	0	0	0	0
Scenario 17	-0.5	-0.5	-0.15	-0.15	0	0	-0.5	-0.5	3.9	3.9	0	0	0	0
Scenario 16	-0.5	-0.5	-0.1	-0.1	0	0	-0.5	-0.5	4.1	4.1	-0.1	-0.1	0	0
Scenario 15	-0.5	-0.5	-0.3	-0.3	0	0	-0.5	-0.5	4.2	4.2	0	0	0	0
Scenario 14	-0.5	-0.5	-0.3	-0.3	0	0	-0.5	-0.5	4.5	4.5	0	0	0	0
Scenario 11	-0.5	-0.5	0	0	0	0	-0.5	-0.5	5	5	-0.5	-0.5	0	0
Scenario 12	-0.5	-0.5	0	0	2	2	-0.5	-0.5	6	6	-0.5	-0.5	-0.3	-0.3
Scenario 1	-0.5	-0.3	0	0	0	0	0	0	0	0	0	0	0	0
Scenario 2	-0.5	-0.5	0	0	0	0	0	0	0	0	0	0	5	5
Scenario 3	-0.5	-0.5	0	0	0	0	0	0	10	10	0	0	5	5
Scenario 4	0	0	0	0	1	1	0	0	100	100	0	0	0	0
Scenario 5	-0.3	-0.3	-0.3	-0.3	1	1	0	0	100	100	0	0	0	0
Scenario 6	-0.3	-0.3	-0.3	-0.3	5	5	-0.8	-0.8	100	100	0	0	0	0
Scenario 7	-0.5	-0.3	-0.3	-0.3	5	5	-1	-1	100	100	-0.3	-0.3	-0.3	-0.3

Table 6.2. Table of Macro level results

ScenarioCode	Objective Value	ObjectiveValue Normalized	Total		
			Forecast	Market Share	CU
Scenario 13	23411840	100.00	16.72%	17.87%	94.81%
Scenario 11	23415978	100.02	16.72%	19.88%	94.81%
Scenario 12	23458271	100.20	16.72%	19.89%	94.81%
Scenario 3	23823264	101.76	16.72%	19.88%	94.81%
Scenario 7	27748242	118.52	16.72%	21.73%	95.00%
Scenario 6	27804474	118.76	16.72%	21.73%	95.00%
Scenario 5	27910260	119.21	16.72%	21.73%	95.00%
Scenario 4	28176005	120.35	16.72%	21.73%	95.00%

Table 6.3. Table of Market and Product Level Results for Market F

	Market F			PG_F_P1		PG_F_P2	
ScenarioCode	Forecast	Satisfaction	CU	Satisfied	Forecast	Satisfied	Forecast
Scenario 13	22.49%	23.44%	89.94%	28.70%	22.13%	18.17%	22.84%
Scenario 11	22.49%	26.57%	89.94%	31.20%	22.13%	21.94%	22.84%
Scenario 12	22.49%	26.57%	89.94%	31.25%	22.13%	21.89%	22.84%
Scenario 3	22.49%	26.57%	89.93%	31.20%	22.13%	21.94%	22.84%
Scenario 7	22.49%	29.03%	90.00%	33.75%	22.13%	24.31%	22.84%
Scenario 6	22.49%	29.03%	90.00%	33.75%	22.13%	24.31%	22.84%
Scenario 5	22.49%	29.03%	90.00%	33.75%	22.13%	24.31%	22.84%
Scenario 4	22.49%	29.03%	90.00%	33.75%	22.13%	24.31%	22.84%

Table 6.4. Table of Market and Product Level Results for Market B

	Market B			PG_B_P1		PG_B_P2		PG_B_P3	
ScenarioCode	Forecast	Satisfaction	CU	Satisfied	Forecast	Satisfied	Forecast	Satisfied	Forecast
Scenario 13	12.34%	13.63%	99.53%	21.82%	12.33%	8.48%	12.01%	10.59%	12.68%
Scenario 11	12.34%	14.79%	99.53%	21.82%	12.33%	10.98%	12.01%	11.56%	12.68%
Scenario 12	12.34%	14.80%	99.53%	21.82%	12.33%	10.98%	12.01%	11.60%	12.68%
Scenario 3	12.34%	14.79%	99.52%	21.82%	12.33%	10.98%	12.01%	11.56%	12.68%
Scenario 7	12.34%	16.18%	100.00%	23.85%	12.33%	12.01%	12.01%	12.68%	12.68%
Scenario 6	12.34%	16.18%	100.00%	23.85%	12.33%	12.01%	12.01%	12.68%	12.68%
Scenario 5	12.34%	16.18%	100.00%	23.85%	12.33%	12.01%	12.01%	12.68%	12.68%
Scenario 4	12.34%	16.18%	100.00%	23.85%	12.33%	12.01%	12.01%	12.68%	12.68%

Pareto Chart presents cost vs. total market share for different strategic decisions. Decision maker should focus to move his/her operation to the efficient frontier by applying related strategies. Decision makers can have this kind of pareto charts for different levels of the system using different kind of key decision variables such as capacity utilization, market share, marketing cost etc. In this fictitious our aim is present the application of our proposed system. Therefore, we will not go further for analysis of different scenarios and their comparison.

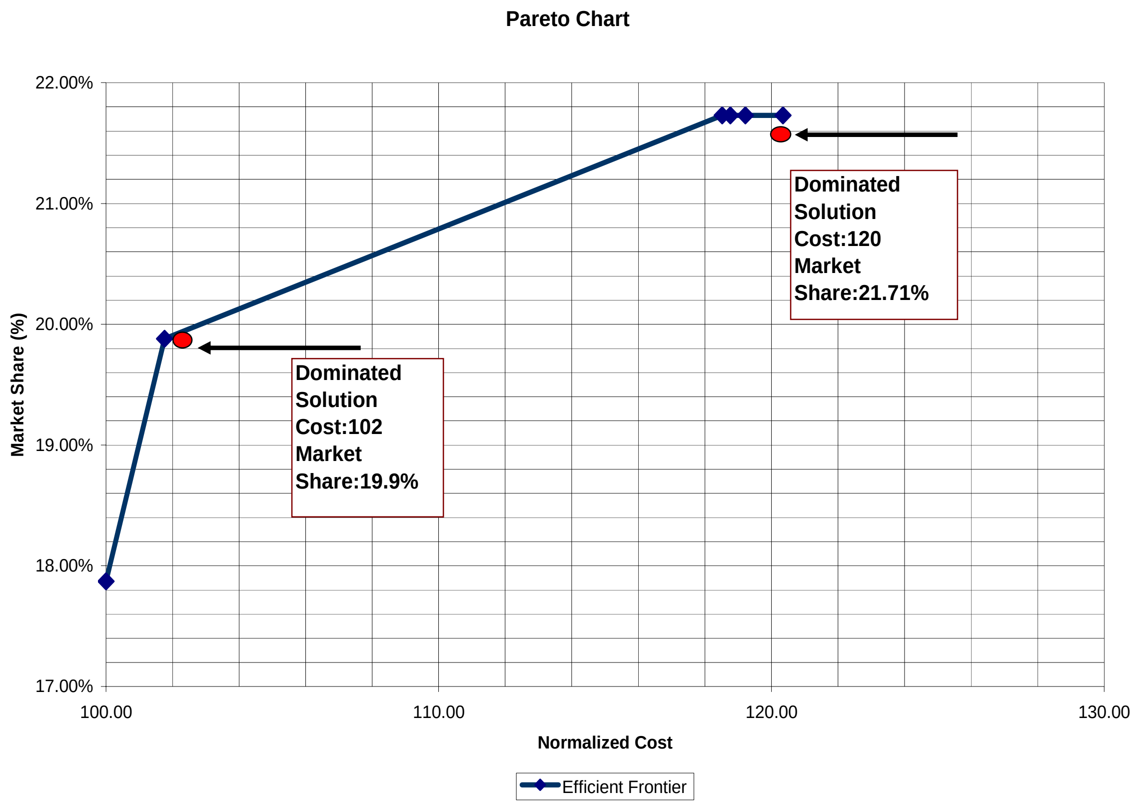


Figure 6.1. Pareto Chart

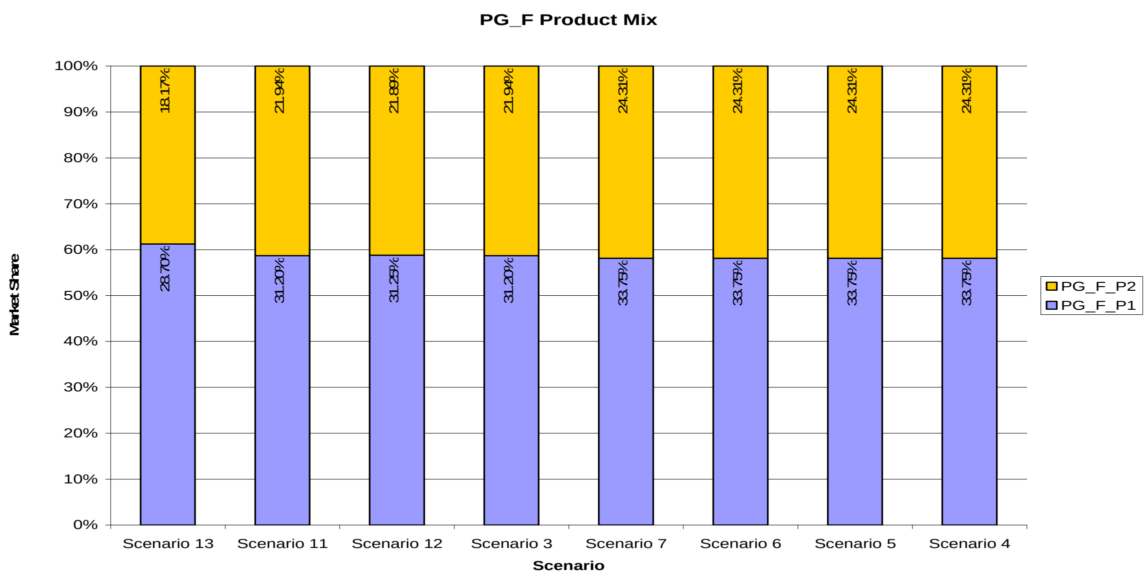


Figure 6.2. Product-Mix for PG-F

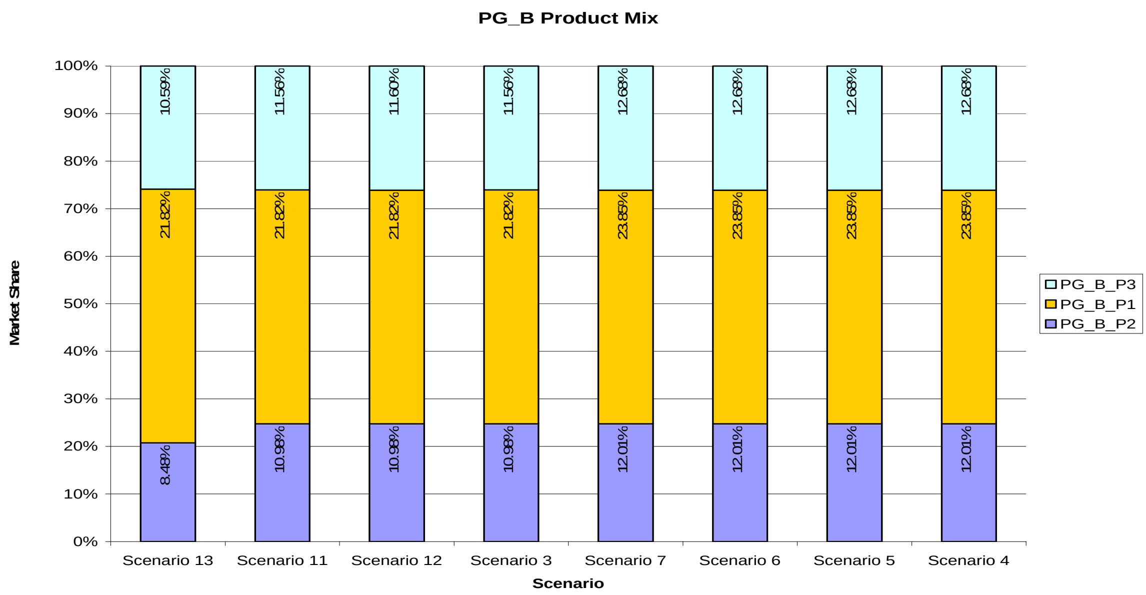


Figure 6.3. Product-Mix for PG-B

7. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In this thesis, we have studied a supply network model including customer-based decisions. First, we have defined the main framework of decision-making process that involves different decision-makers. Our framework includes three major corporate functions such as supply network function, sales & marketing function and cost function. Then, based on this framework, we have developed a linear programming model to manage these strategies. On top of this, as mentioned previously, developing a single large model is not sufficient by itself. A well-designed decision support system should have the features to manage this model. Therefore, several decision nodes and decision multiples have been implemented on top of the mathematical model and we have practiced our decision support system in a sample scenario. A large scale linear programming model can be managed, resized and used after and after for what-if analysis by implementing manipulator factors for the cost terms in the objective function and holding other functions unchanged.

Demand planning process drives sales targets from historical sales data and strategic company targets. On the other hand, our results suggest that this may not be the case. Company should focus on products that should be sold for most profitable product mix. Including the target levels of market penetration, market volume and marketing costs this demand and market planning can be achieved. Since our model both includes the supply network function and sales and marketing function, implicit trade-offs between the decision makers also handled. In order to have more precise and customized results, some future work directions can be summarized as

- *Promotion Planning*: Our key decision parameters such as additional demand, unsatisfied demand, delivered quantity, produced quantity and ending inventory gave acceptable results. Especially marketing related variables provide hope for future research. Adding new decision variables related with sales activities such as period end bonus and discount paid in cash, one can manage the promotion planning which significant for companies in the FMCG sector. From our surveys with executives from different companies and our study presented in this thesis, it was clearly observed that including these decision-variables would add power to the model. As mentioned in previous chapters, our model includes several levels of dimensions in every part of the supply network. If the user can define appropriate cut-off lines for marketing costs in terms of marketing activity, promotion planning can be executed from strategic level to operational level.

- *Planning based on dynamic goals:* In our current design, any decision given in period t does not affect the targets of period t+1. In reality, after a level of saturation is reached, these targets can change. Therefore, introducing this concept into the model may bring benefit to the future researchers. On top of this, an important assumption is the linearity assumptions for the cost effect. This may not reflect the real life problems and some nonlinear cost relationships can be included in the model to manage different kind of relations between the key decision variables.
- *Cost Planning:* We believe that defining Cost, as a separate functionality is a breakthrough solution for both decision-making and cost analysis. Especially in the later case, cost figures can be defined as a key decision variable to compute cost margins or optimum budget levels to reach a business target.

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