Iranian Journal of Management Studies (IJMS) *http://ijms.ut.ac.ir/*
Vol. 10, No.2, Spring 2017 *Print ISSN: 2008-7055*
pp. 335-364 *Online ISSN: 2345-3745*
DOI: 10.22059/ijms.2017.218842.672334

Towards Supply Chain Planning Integration: Uncertainty Analysis Using Fuzzy Mathematical Programming Approach in a Plastic Forming Company

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(Received: November 2, 2016; Revised: May 6, 2017; Accepted: May 23, 2017)

Abstract

Affected by globalization and increased complexity, supply chain managers have learned about the importance of Sales and Operations Planning (S&OP). However, in large scale supply chains, S&OP has received little attention, by both academics and practitioners. The purpose of this manuscript is to investigate the advantages of S&OP process using a mathematical modeling approach in a large scale plastic forming company. Three Fuzzy Mixed Integer Linear Programming (f-MILP) models were developed in this article for this reason: A Fully Integrated S&OP (FI-S&OP) model, a Partially Integrated S&OP (PI-S&OP) model, and a decoupled planning (DP) model. Also, Triangular Fuzzy Numbers (TFNs) are utilized to represent uncertainty and vagueness associated with real world operations. All the models are developed for a multi-site manufacturing company, which is coping with different raw material suppliers and Third Party Logistics (3PLs), Distribution Centers (DCs), and customers with a wide range of product families. Finally, all the models are applied in a real case in a plastic manufacturing company in Iran. The results demonstrate the superiority of FI-S&OP over other models.

Keywords

Fuzzy mixed integer linear programming (f-MILP), Make to stock, Plastic forming industry, Sales and operations planning (S&OP).

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Introduction

Confronting with competitiveness side effect in markets in extremely emerging business environment, companies are pushed to improve their manufacturing infrastructure by more advanced planning and concentrating on their supply chains (Alavidoost et al., 2016; Alavidoost & Nayeri, 2014; Nemati et al., 2017). Supply chain is about gathering around traditionally disconnected divisions from the whole business, in order to orchestrate the processes and activities in a more efficient way (Alavidoost et al., 2015a). Under Supply Chain Management (SCM) and Supply Chain Planning (SCP) paradigms as umbrella, S&OP is spreading worldwide as a supply chain planning integration concept. S&OP is a monthly planning process at tactical level which is leaded by the company's top management and its function is to balance demand and supply in order to maximize production, distribution, and procurement utilization, also to analyze their financial impacts, so that the top manager ensures the alignment and coordination of the functional divisions with the enterprise's global strategy. In fact, S&OP is a mid-term planning process that evaluates and integrates the operational plans from all functional divisions to present the output as a set of compatible plans to coordinate, balance and control the performance of the total chain (Ling, 2002).

Sales and operations are the heart of today's businesses and the decisions made in these areas will intensively affect the financial performance, operational efficiency and service level of the whole organization. Traditionally, the decisions in these two areas have been taken discretely with no or little coordination with each other so that planning processes of sales, production, distribution and procurement is performed discretely, based on different and sometimes conflicting logics. In this decoupled planning environment, the sales planning is performed centrally and the other planning functions are performed in manufacturing sites, locally. Sales decisions are mainly being made focusing on sales volume without taking into account the total profit of the organization while production decisions are concentrated on minimizing production costs and maximizing material, equipment, and labor efficiency. Fundamentally, these two functions have different responsibilities and Key Performance Indicators (KPI) that tend to be locally optimized have little focus on total organization profitability (Wahlers & Cox III, 1994).

In broader scope, supply chain includes four essential functions: Sales, distribution, production, and procurement (Fleischmann et al., 2015). Traditionally, these steps are coupled with each other by *stocks*. Discrete governance environment implies that the decisions are being made independently in each functional division. Although this approach may reduce the amount of complexity, it ignores the inter-dependencies among functional areas and eliminates the cost reduction opportunities and in the worst case, it can lead to inapplicable decisions. To encounter today’s extremely challenging markets, the organizations are mobilizing from traditional discrete decision making to more centralized control over supply chain activities to reduce the total supply chain cost, and improve financial performance and service level as well.

Fleischmann et al. (2015) developed a two-dimensional matrix that divides supply chain planning process into four steps of procurement, production, distribution and sales planning (Fig. 1).

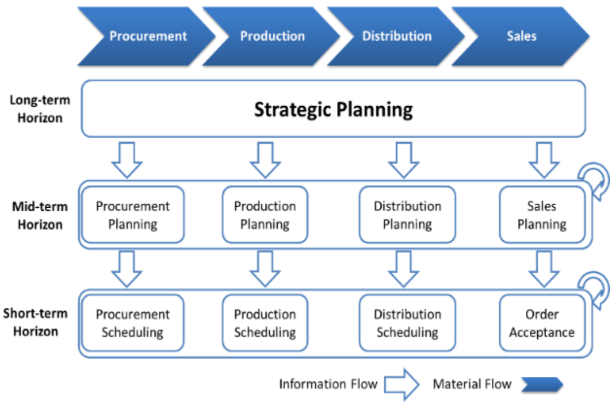

Fig. 1. SCP matrix, adapted from Fleischmann et al. (2015)

The S&OP term is originated from Manufacturing Resource Planning (MRP II) papers, where some authors used it as a substitute for Aggregated Production Planning (APP). Since 1980, the concept of S&OP expanded and sales planning attached to operations planning part. Thus, S&OP consists of two distinct pieces: Production planning, where issues such as inventory and capacity needs, as well as backorder levels have been considered, and demand-based sales planning (Olhager et al., 2001; Wallace, 2004). This concept of S&OP is still being used by a lot of authors and researchers. The relationship between operations and sales functional areas and the role and importance of each one is pointed by Wahlers and Cox III (1994). They propose that the collaboration between these two functions can be considered as an important competitive KPI for further improvements in organization’s total performance. The aim is to mix the sales and operation plans to establish balance between production capacity and demand. To achieve this objective, two types of planning decisions could be imagined, from one aspect, we can change the market demand to be compared with production limitations (which is the aggressive view), and on the other hand, we can change the capacities to match the demand (which is called the reactive view) (Krajewski & Ritzman, 2001). The reactive approach is used by Olhager et al. (2001). They introduced S&OP as a mid-term production planning approach to satisfy demand. These studies, describe S&OP as a tactical level planning task which vertically connects long-term business strategies to the execution as well as linking demand to supply capacity, horizontally (Wallace, 2004).

Until today, the researches around S&OP were mainly focused on its definitions, procegures, functions, and practical case studies, and very few works have investigated the advantages of implementing S&OP from mathematical modeling point of view. Considering the difficulties that plastic forming companies deal with in traditional planning and decision making process, and taking into account the many opportunities that integrated supply chain planning would bring for such companies, we are persuaded enough to fill this gap by proposing a mathematical modeling approach to quantitatively evaluate and compare the advantages of fully integrated S&OP process with no and less integrated planning approaches. Hence, three different planning approaches will be considered in this article in order to compare the past, present and future situation of the studied company from SCP point of view: FI-S&OP, PI-S&OP, and DP approach.

This paper proceeds as follows: We start section two with a literature review, where the fundamentals of S&OP are presented along with current trends review. In section three, three mathematical models will be developed representing the FI-S&OP, PI-S&OP, and DP approaches, in the context of a multi-site forming network. The implementation of the mentioned models in a real industrial condition in a forming company will be presented in section four. The numerical results and sensitivity analysis of the models are illustrated in section five. Finally, the conclusions followed by future research opportunities will be available in section six.

Background

Reviewing the recent studies indicates an increasing trend in utilizing S&OP in supply chain coordination and value creation. These studies look at S&OP as a coordination function that adopts customer demand with the supply via confronting it to marketing, production, procurement, logistic, and financial activities and decisions (Feng et al., 2008). This idea expanded by Cecere (2006) proposing that S&OP must synchronize customer demand with supply capacity, aligned with the business strategy in a profitable way. Until today, the expanded models of S&OP were mostly APP based models that determine the amount to be produced, inventory and backorder levels and the needed amount of manpower based on forecast, to minimize the minimum production cost (Feng et al., 2013; Olhager et al., 2001).

Rizk, Martel, and D’Amours (2006) addressed the dynamic production and distribution planning problem in wood industry, in order to minimize the distribution cost subject to the economy of scale. Ouhimmou, D’Amours, Beauregard, Ait-Kadi, and Chauhan (2008) presented an integrated procurement, sawing, drying, and distribution plannning model for a multi-site, multi-period problem in furniture industry. They solved their model through time decomposition heuristic algorythm. Feng et al. (2013) simulated an MILP model of maximizing total supply chain profit to solve the S&OP problem in oriented strand board industry assuming deterministic demand in a make-to-order environment. The results indicated superior performance of integrated supply chain based planning approach over the discrete planning approach.

Pauls-Worm, Hendrix, Haijema, and van der Vorst (2014) have studied the practical production planning problem of a food producer with perishable products. While a setup cost was incurred in every production run, the producer had to deal with unit production cost, unit holding cost and unit cost of waste. They formulate a single item and single echelon production planning problem as a stochastic programming model with a chance constraint. The model assumed zero lead time and backlogging of shortages. They show the viability of the approach by numerical experiments. Baumann and Trautmann (2014) have presented a novel hybrid method for the short-term scheduling of FMCG production processes. They have presented strategies for integrating MILP models into the construction and improvement phases of the hybrid method to efficiently solve the scheduling. Pant, Prakash, and Farooquie (2015) have studied three prevalent types of dairy supply chains in India and presented a framework for transparency, traceability, and information flow for management of dairy supply chain networks. The findings would be useful for policy makers in framing standards and effective regulations. Wari and Zhu (2016) have presented a multi-week MILP scheduling model for a food processing facility. The model was tested on a set of cases from the literature, and its results were compared to the results of problems solved using hybrid MILP-heuristics methods in the literature. The result showed that the proposed MILP was able to handle multi-week scheduling efficiently and effectively within a reasonable time limit. Kır and Yazgan (2016) have studied on a single machine scheduling problem in dairy industry. They have proposed an integrated algorithm by integration of Tabu search and genetic algorithm, to solve the problem, subject to variables of due dates, earliness and tardiness penalty costs and sequence dependent setup times. The main purpose was to meet demands of customers, while total penalty costs of earliness and tardiness were minimized. A hierarchical approach consisting of Tabu search and a genetic algorithm was proposed to generate proper schedules. An instance of the algorithm was demonstrated to illustrate the applicability. Touil, Echchatbi, and Charkaoui (2016) have developed a MILP model for a production scheduling problem in a multistage, multi-product milk processing facility in Morocco. The model included several technological constraints typically arising in the dairy industry, such as dependent sequence changeover time, machine speed, and taking into account the packaging timing and capacity constraints, in order to minimize the makespan. The numerical results demonstrate the efficiency of the proposed model.

Until today, the concept of S&OP has been developed gradually. This evolution, started from Aggregated Production Planning to Joint Sales and Production Planning named here as Partially Integrated S&OP (PI-S&OP) and recently Supply Chain based Sales and Operations Planning which we named concisely as Fully Integrated S&OP (FI-S&OP). Although, many studies have been conducted around coordination of different functional areas in supply chain, very few studies have been dedicated to address the planning integration of mentioned four functional areas simultaneously, and most of the studies are focused on some selected functions, mostly production and distribution, at planning and scheduling levels. Besides, to our best knowledge, no research exists on modeling fully integrated S&OP in plastic forming industry so far.

Reviewing the upcoming literature, our study is going to investigate the fully integrated sales and operations planning process to quantitatively evaluate the added value of such an integration in a manufacturing supply chain. To attain this goal, we initially need to develop three mathematical models of FI-S&OP, PI-S&OP, and DP in the context of forming supply chain. Considering the point that every theoretical model has to work properly in a simulated environment before implementation in real world, we intend to simulate the proposed model to make sure of its perfect functionality. In the next step, the results will be implemented in a real case study in forming industry in Iran.

Research Methodology

As mentioned, building on the previous studies, we intent to develop a mathematical model to measure the added value of implementing S&OP. Using the supply chain planning matrix of Fleischmann et al. (2015), the total process of S&OP can be depicted in Figure 2.

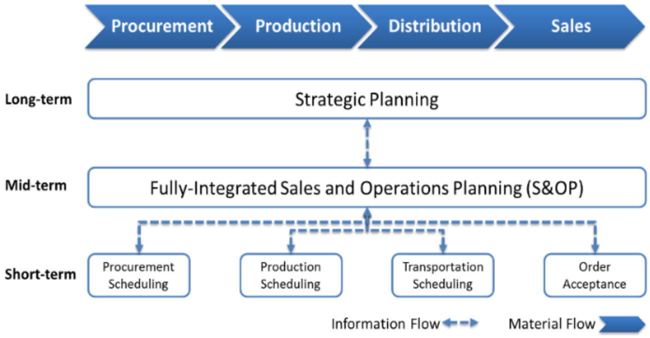

Fig. 2. Fully integrated sales and operations planning

The centralized FI-S&OP model will propose a specific plan for each manufacturing site. According to the specified plans, each site can prepare its operation scheduling as well (Fig. 3). To formulate the model, we consider a case in the forming industry. The target company has three alternative factories in three different locations (Fig. 4).

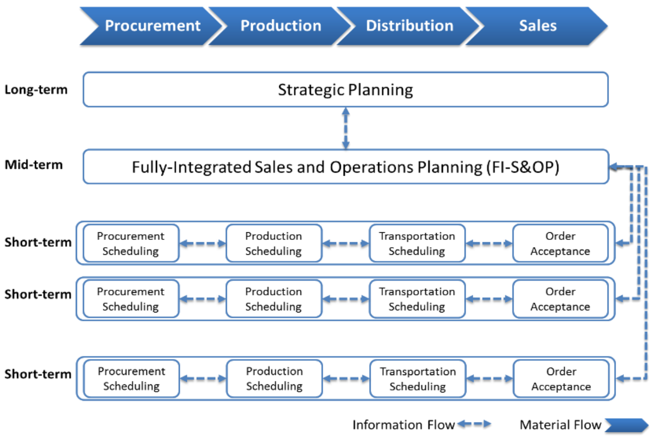

Fig. 3. Fully integrated multi-site sales and operations planning

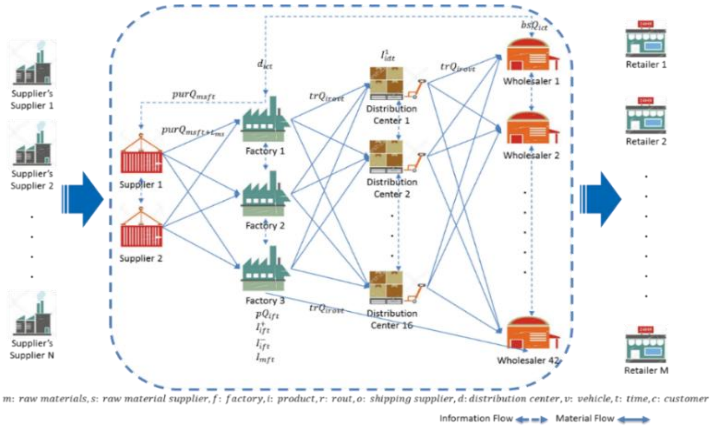

Fig. 4. Supply network of the studied company

The sales orders are passed to each factory, separately. Each factory has a finite specified capacity for each product family and production is carried out in batch. Based on a Bill of Materials (BOM) and routing, each product family contains specific raw materials with different amounts, while the major components for most of the products are milk and cream. Most of the product families have their particular production lines, while a few ones use common production lines, thus there would be a change over time (set-up time) for changing the line to produce another product family. The set-up time and naturally set-up cost are different for each production line. Each production family consists of numerous products. Production is based on MTS procedure and the warehousing capacity is limited in each site. As shown in Figure 4, the finished products are delivered to customers which are all wholesalers, straightly from the factory or through the DCs. The company has owned 42 DCs in different geographical locations with different capacities.

The Fuzzy FI-S&OP Model

After reviewing the assumptions (Fig. 3), now we can present our multi-site FI-S&OP f-MILP model through the integration of sales, production, distribution, and procurement planning in enterprise level. The aim is to maximize the net profit of total enterprise from balancing the sales incomes and supply chain costs, assuming cumulative capacity constraints of total supply chain in period T. The entry data and outgoing decisions are shown in Figure 5. Indices, sets, parameters, and decision variables as well as the mathematical model are formulated as bellow:

***Indexes and Sets*:**

$f \in F$	set of factories
$i \in I$	set of product families
$t \in T$	set of time periods
$c \in CC$	set of contract customers
$c \in NC$	set of non-contract customers (c= cc U NC)
$c \in C$	set of customers
$s \in S$	set of raw material suppliers
$s \in CS$	set of contract raw material suppliers
$s \in NS$	set of non-contract raw material suppliers (S= CS U NS)
$m \in M$	set of raw materials
$j \in J$	set of raw material categories $(m \in j)$
$o \in O$	set of outbound shipping suppliers
$d \in D$	set of distribution centers
$v \in V$	set of vehicle types
$r \in R_{fd}$	set of routes from factory *f* to distribution center *d*
$r \in R_{fc}$	set of routes from factory *f* to customer *c*
$r \in R_{dc}$	set of routes from *d* to customer *c*
$r \in R$	set of all routes, $R = R_{f,d} \cup R_{f,c} \cup R_{d,c}$

***Parameters*:**

<u>*Sales*</u>:

$\widetilde{sP}_{ict}$	sales price of product family *i* to customer c $(c \in C)$ in period *t*
d_{ict}	demand from customer c $(c \in C)$ for product family *i* in period *t*
$dmin_{ict}$	minimum demand quantity from customer c $(c \in C)$ for product family *i* in period *t*

<u>*Production*</u>:

$pCap_{ift}$	production capacity for product family *i* of factory *f* in period *t*
$epCap_{ift}$	estimated production capacity for product family *i* of factory *f* in period *t*
$\widetilde{epC}_{ift}$	estimated product cost of producing unit quantity of product family *i* at factory *f* in period *t*
α_{ift}	capacity consumption for producing one batch of product family *i* at factory *f* in period *t*
β_{ift}	production batch size of product family *i* at factory *f* at period *t*
$\widetilde{pC}_{ift}$	unit production cost to produce product family *i* at factory *f* at period *t*
$\widetilde{sC}^1_{ift}$	expected set-up cost for product family *i* at factory *f* at period *t*
st_{ift}	expected set-up time for product family *i* at factory *f* at period *t*
$\widetilde{hC}^1_{ift}$	inventory holding cost for unit quantity of product family *i* at factory *f* at period *t*
$\widetilde{boC}_{ift}$	backlog cost for unit quantity of product family *i* at factory *f* at period *t*
I^-_{if0}	initial backlog quantity of product family *i* in factory *f* at period $t = 0$
$hCap^1_f$	finished goods warehouse inventory capacity of factory *f*
G	big number

<u>*Distribution*</u>:

$\widetilde{tfC}_{rov}$	shipping fixed cost on route *r* of supplier *o* $(o \in O)$ using vehicle type *v*
$\widetilde{tvC}_{irov}$	shipping variable cost for family *i* on route *r* of supplier *o* $(o \in O)$ using vehicle type *v*
a_{iv}	vehicle capacity absorption coefficient per unit of product family *i*
$\widetilde{hC}^2_{id}$	inventory holding cost for unit quantity of product family *i* at distribution center *d*
$hCap^2_d$	inventory holding capacity of distribution center d
$\widetilde{trC}_{id}$	transhipment cost of unit quantity of product family *i* through distribution center *d*

$trCap_{otv}$ shipping capacity of supplier o $(o \in O)$ at period *t* with vehicle *v*
$vCap_v$ vehicle capacity of vehicle type *v*
$KCap_{fv}$ expedition capacity of factory *f* for vehicle category *v*

<u>*Procurement*</u>:

u_{mif} consumption of raw material *m* for producing unit quantity of product family *i* at factory *f*
$mCap_{jf}$ inventory capacity of raw material category *j* at factory *f*
$sCap_{st}$ supply capacity of supplier s $(s \in S)$ in period *t*
$Qmin_{ms}$ minimum contract purchase quantity for raw material *m* from supplier *s* $(s \in CS)$
SS_{mf} safety stock of raw material *m* at factory *f*
$\widetilde{purC}_{mst}$ unit purchase cost of raw material *m* from supplier *s* $(s \in S)$ in period *t*
$\widetilde{sC}^2_{mst}$ set-up cost of purchasing raw material *m* from supplier *s* $(s \in S)$ in period *t*
$\widetilde{hC}^3_{mf}$ unit inventory holding cost of raw material *m* at factory *f*
L_{ms} lead-time of procuring raw material *m* from supplier s $(s \in S)$

$\boldsymbol{Decision\ Variables}$:

<u>*Sales*</u>:

sQ_{ict} sales quantity of product family *i* to customer c $(c \in C)$ in period *t*
bsQ_{ict} backlogged sales quantity for product family *i* to customer c $(c \in C)$ in period *t*

<u>*Production*</u>:

pQ_{ift} production quantity of product family *i* at factory *f* in period *t*
pbN_{ift} number of production batches of product family *i* at factory *f* in period *t*
I^+_{ift} inventory quantity of product family *i* in factory *f* at the end of period *t*
I^-_{ift} backlog quantity of product family *i* in factory *f* at the end of period *t*
X_{ift} binary variable; 1, if set up is required; 0, otherwise

<u>*Distribution*</u>:

trQ_{irovt} shipping quantity of family *i* by supplier o $(o \in O)$ on route *r* using vehicle *v* in period *t*
tN_{rovt} number of truckload from supplier o $(o \in O)$ on route *r* using vehicle *v* in period *t*
I^1_{idt} inventory of product family *i* in distribution center *d* at the end of period *t*

<u>*Procurement*</u>:

$purQ_{msft}$ purchasing quantity of raw material *m* from supplier s $(s \in S)$ by factory *f* in period *t*
I_{mft} inventory of raw material *m* at factory *f* at the end of period *t*
y_{mst} binary variable; *1*, if for material *m* from supplier s $(s \in S)$ in period *t*; *0*, otherwise

Objective Function:

$$
\begin{aligned}
Z = \max &\left(\sum_{i\in I}\sum_{c\in C}\sum_{t\in T}\widetilde{sP}_{ict}.\,sQ_{ict}\right)\\
&-\left\{\sum_{i\in I}\sum_{f\in F}\sum_{t\in T}\left(\widetilde{pC}_{ift}.\,pQ_{ift}+\widetilde{sC}^1_{ift}.\,X_{ift}+\widetilde{hC}^1_{ift}.\,I^+_{ift}+\widetilde{boC}_{ift}.\,I^-_{ift}\right)\right\}\\
&-\left\{\sum_{i\in I}\sum_{r\in R_{f,d}\cup R_{f,c}\cup R_{d,c}}\sum_{o\in O}\sum_{v\in V}\sum_{t\in T}\left(\widetilde{tvC}_{irov}.\,trQ_{irovt}+\widetilde{tfC}_{rov}.\,tN_{rovt}\right)\right.\\
&\left.+\sum_{i\in I}\sum_{r\in R_{f,d}}\sum_{o\in O}\sum_{v\in V}\sum_{t\in T}\left(\widetilde{trC}_{ir}.\,trQ_{irovt}\right)+\sum_{i\in I}\sum_{d\in D}\sum_{t\in T}\left(\widetilde{hC}^2_{id}.\,I^1_{idt}\right)\right\}\\
&-\left\{\sum_{m\in M}\sum_{s\in S}\sum_{f\in F}\sum_{t\in T}\left(\widetilde{purC}_{mst}.\,purQ_{msft}\right)\right.\\
&\left.+\sum_{m\in M}\sum_{s\in S}\sum_{t\in T}\left(\widetilde{sC}^2_{mst}.\,y_{mst}\right)+\sum_{m\in M}\sum_{f\in F}\sum_{t\in T}\left(\widetilde{hC}^3_{mf}.\,I_{mft}\right)\right\}
\end{aligned}
\tag{1}
$$

Constraints:

Sales:

$$\mathrm{dmin}_{ict} \leq d_{ict} + (1 - K_{ict})G \quad \forall c \in C, i, t \tag{2}$$

$$sQ_{ict} \leq d_{ict} * K_{ict} \quad \forall c \in C, i, t \tag{3}$$

$$sQ_{ict} \geq \mathrm{dmin}_{ict} * K_{ict} \quad \forall c \in C, i, t \tag{4}$$

Production:

$$\sum_{f\in F}(pQ_{ift} + I^{+}_{ift-1} - I^{-}_{ift-1} - I^{+}_{ift} + I^{-}_{ift}) + \sum_{d\in D}(I^{1}_{idt-1} - I^{1}_{idt}) = \sum_{c\in C} sQ_{ict} \quad \forall i, t \tag{5}$$

$$\sum_{f\in F} I^{-}_{ift} = \sum_{c\in C} bsQ_{ict} \quad \forall i, t \tag{6}$$

$$pQ_{ift} = pbN_{ift}.\beta_{ift} \quad \forall i, f, t \tag{7}$$

$$G.X_{ift} \geq pQ_{ift} \quad \forall i, f, t \tag{8}$$

$$\alpha_{ift}.pbN_{ift} + st_{ift}.X_{ift} \leq pCap_{ift} \quad \forall f, t \tag{9}$$

$$\sum_{i\in I} I^{+}_{ift} \leq hCap^{1}_{f} \quad \forall f, t \tag{10}$$

$$I^{-}_{ift=0} = I^{-}_{ift=T} = I^{-}_{ifo} \quad \forall i, f \tag{11}$$

Distribution:

$$sQ_{ict} + bsQ_{ict-1} - bsQ_{ict} = \sum_{o\in O}\sum_{r\in R_{f,c}\cup R_{d,c}}\sum_{v\in V} trQ_{irovt} \quad \forall c \in C, i, t \tag{12}$$

$$pQ_{ift} + I^{+}_{ift-1} - I^{+}_{ift} = \sum_{o\in O}\sum_{r\in R_{f,d}\cup R_{f,c}}\sum_{v\in V} trQ_{irovt} \quad \forall i, f, t \tag{13}$$

$$\sum_{o\in O}\sum_{r\in R_{f,d}}\sum_{v\in V} trQ_{irovt} + I^{1}_{idt-1} - I^{1}_{idt} = \sum_{o\in O}\sum_{r\in R_{d,c}}\sum_{v\in V} trQ_{irovt} \quad \forall i, d, t \tag{14}$$

$$tN_{rovt} \geq \sum_{i\in I} \frac{a_{iv}.trQ_{irovt}}{vCap_{v}} \quad \forall o \in O, r, v, t \tag{15}$$

$$\sum_{r\in R} tN_{rovt} \leq trCap_{otv} \quad \forall o \in O, v, t \tag{16}$$

$$\sum_{r\in R_{d,f}}\sum_{o\in O}\sum_{v\in V} tN_{rovt} \leq KCap_{fv} \quad \forall f, t \tag{17}$$

Procurement:

$$\sum_{s\in S} purQ_{msft-L_{ms}} + I^{2}_{mft-1} - I^{2}_{mft} = \sum_{i\in I} u_{mif}.pQ_{ift} \quad \forall m, f, t = 1 - L_{m,s}, \dots, T \tag{18}$$

$$I^{2}_{mft} - SS_{mf} \geq 0 \quad \forall m, f, t \tag{19}$$

$$\sum_{m\in j} I^{2}_{mft} \leq mCap_{jf} \quad \forall j, f, t \tag{20}$$

$$\sum_{m\in M}\sum_{f\in F} purQ_{msft} \leq sCap_{st} \quad \forall s \in S, t \tag{21}$$

$$G.y_{mst} \geq \sum_{f\in F} purQ_{msft} \quad \forall s \in S, m, t \tag{22}$$

$$\sum_{f\in F}\sum_{t\in T} purQ_{msft} \geq Qmin_{ms} \quad \forall s \in CS \tag{23}$$

$$
\begin{aligned}
&sQ_{ict}, bsQ_{ict}, pQ_{ift}, I^{+}_{ift}, I^{-}_{ift}, trQ_{irovt}, I^{1}_{idt}, purQ_{msft}, I^{2}_{m,f,t} \ \geq 0 \\
&X_{ift}, tN_{rovt} \ \text{are positive integers, and} \\
&X_{ift} \in \{0,1\}, y_{mst} \in \{0,1\} \quad \forall c, i, f, t, r, v, d, m, o\ (o \in O), s\ (s \in S)
\end{aligned} \tag{24}
$$

In the Formula (1), the first bracket addresses the total profit, gained from the sales. The second bracket respectively covers the production, set-up, inventory holding, and backorder costs. The third bracket represents the total transportation costs of finished products from factory to DCs, factory to customers and DCs to customers, as well as the inventory holding costs in DCs. The Restrictions (2) and (3) address the sales decisions and the fact that sales decisions should first satisfy the contract demands in period t and then, consume the remained capacity to satisfy further added contractual demands and non-contractual demands as well. Thereby, the sales managers can decide whether to take the demand as backorder and satisfy it in next period or reject them. In both manners, the back sales amount should not be more than the sales amount (Restriction 4).

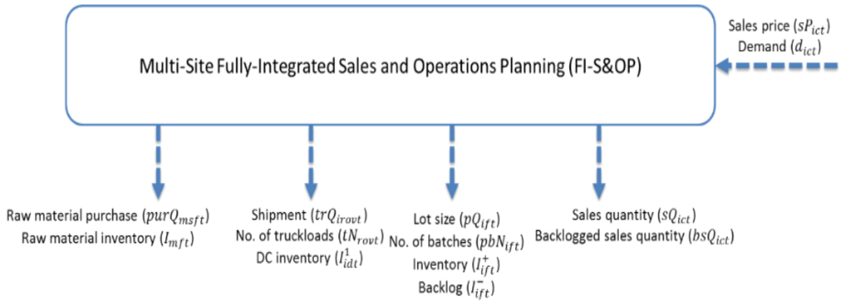

Fig. 5. Inputs and outputs of FI-S&OP model

Restriction (5) joints the production, distribution and sales planning to each other and delivers a smooth consolidated physical flow over the chain. Restriction (6) converts the backlogs into backlogged sale. Restriction (7) guarantees that production is take place always in batch sizes. Restriction (8) examines if a set-up cost is assigned to start producing product family i or not. Restriction (9) sets the production capacity which delivers the message that the total time of production and set-up should not go beyond the total available time in period t. Restriction (10) defines the capacity of finished goods warehouse. The condition of opening and closing backlogs is presented in Restriction (11).

Restriction (12) weaves the sales and distribution decisions together (Fig. 4). Restriction (13) links the production and distribution decisions together and show the balance in factory point (Fig. 4). These constraints imply that the product delivered from the factory should be equal to the amounts produced plus the opening stock minus the closing stock. Restriction (14) addresses the balance in inventory flow in DCs, which means that the total delivery to a DC, plus the opening stock, minus the closing stock should be equal to total delivery from the DC. Restriction (15) quantifies the needed number of vehicle types from each shipping suppliers. Restriction (16) shows the capacity of shipping suppliers and restriction (17) depicts the loading and dispatching capacity of each factory. Restriction (18) joints the procurement and production planning together, with balancing of materials in factory point. Holding policy of raw material is described in Restriction (19) and the warehousing capacity of raw material inventories is addressed in Restriction (20). Restriction (21) describes the procurement limitations of raw materials as a function of t, so that it can cover the consumption seasonality. Restriction (22) is the raw materials ordering policy which assumes demands can be allocated to the production sites, in the way that the total ordering cost will be minimum level. Restriction (23) implies that the purchase amount from the contract suppliers should be at least equal to the committed amount. Restriction (24) is about defining the range of each variable.

The Fuzzy PI-S&OP Model

Multi-site PI-S&OP model addresses the state that sales and production decisions are being made together and distribution and procurement decisions are being made in each site locally (Fig. 6). Hence, the PI-S&OP model encompasses three sub-models: A sales and production planning sub-model, a distribution sub-model and procurement planning sub-model. Sales and backlogged sales of each site are depicted through sales and production sub-model due to be used in distribution sub-model. In distribution sub-model, DCs are looked only as dock stations. Since all factories are linked to all DCs, the distribution planning of each site is performed separately and independently. The three sub-models are defined as follows:

Sales & production planning sub-model

This model tries to maximize the net profit of the enterprise by subtracting the production costs from the sales revenue.

Objective Function:

$$\text{Max: } \sum_{i\in I}\sum_{f\in F}\sum_{t\in T}\Big(\sum_{c\in C}\widetilde{sP}_{ict}.sQ_{icft} - \widetilde{pC}_{ift}.pQ_{ift} - \widetilde{sC}^{1}_{ift}.X_{ift} - \widetilde{hC}^{1}_{ift}.I^{+}_{ift} - \widetilde{boC}_{ift}.I^{-}_{ift}\Big) \quad (25)$$

Subject to following constraint plus (7) − (11):

$$\sum_{f\in F}(sQ_{icft} - bsQ_{icft}) \geq dmin_{ict} \quad \forall c \in CC, i, t \quad (26)$$

$$\sum_{f\in F} sQ_{icft} \leq d_{ict} \quad \forall c \in C, i, t \quad (27)$$

$$bsQ_{icft} \leq sQ_{icft} \quad \forall c \in C, i, f, t \quad (28)$$

$$pQ_{ift} + I^{+}_{i,f,t-1} - I^{-}_{i,f,t-1} - I^{+}_{i,f,t} + I^{-}_{i,f,t} = \sum_{c\in C} sQ_{icft} \quad \forall i, f, t \quad (29)$$

$$I^{-}_{i,f,t} = \sum_{c\in C} bsQ_{icft} \quad \forall i, f, t \quad (30)$$

$$sQ_{icft}, bsQ_{icft}, pQ_{ift}, I^{+}_{i,f,t}, I^{-}_{i,f,t} \geq 0, pbN_{ift} \text{ is positive integer, and } sQ_{ift} \in \{0,1\} \quad \forall c, i, f, t \quad (31)$$

Restrictions (26), (27) and (28) are the modified Constraints (2), (3) and (4), which sales and backlogged sales have been specified before in each site. Restrictions (29) and (30) are the modified Constraints (5) and (6) which transfer the inventories of DCs, while focusing on the balance of the inventory flow. Restriction (S24) is the modified positive restriction which includes only sales and production decisions.

Distribution planning sub-model

Based on the results of the joint sales-production sub-models, the distribution sub-model determines which type of transportation vehicle and how many, from which shipping supplier is needed to deliver products. The objective tries to minimize the total cost of shipping and transshipments.

Objective Function

$$\text{Min: } \sum_{f\in F}\sum_{o\in O}\sum_{i\in I}\sum_{v\in V}\sum_{t\in T}\left\{\sum_{r\in R}\left(\widetilde{tvC}_{irov}.\,trQ_{irovt}+\widetilde{tfC}_{rov}.\,tN_{rovt}\right)+\sum_{r\in R_{f,d}}\widetilde{trC}_{id}.\,trQ_{irovt}\right\} \quad (32)$$

Subject to following restrictions plus $(15)-(17)$:

$$\sum_{f\in F}(sQ_{ifct}+bsQ_{ifct-1}-bsQ_{ifct})=\sum_{o\in O}\ \sum_{r\in(R_{f,c}\cup R_{d,c})}\ \sum_{v\in V}trQ_{irovt} \quad \forall c\in C,i,t \quad (33)$$

$$\sum_{o\in O}\ \sum_{r\in R_{f,d}}\ \sum_{v\in V}trQ_{irovt}=\sum_{o\in O}\ \sum_{r\in R_{d,c}}\ \sum_{v\in V}trQ_{irovt} \quad \forall i,d,t \quad (34)$$

$$trQ_{irovt}\geq 0 \text{ and } tN_{srvt} \text{ is positive integer} \quad \forall\ o\in O,i,r,v,t \quad (35)$$

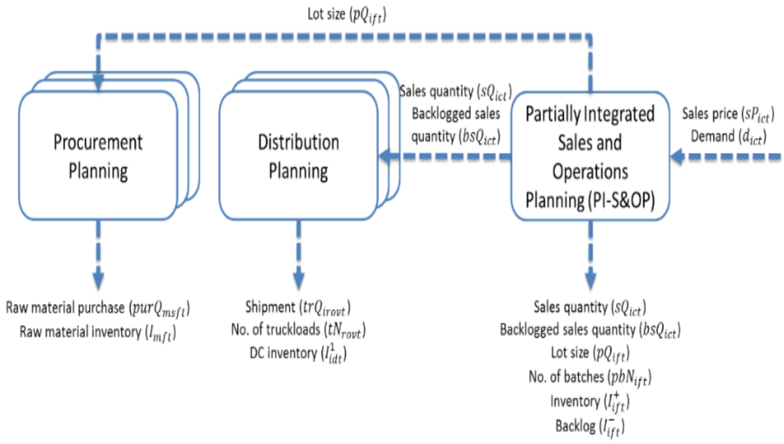

Fig. 6. Inputs and outputs of PI-S&OP

Restriction (33) is the modification of Restriction (12), which the sales decision variables are set in each manufacturing site, independently. Restriction (34) are the modified Restriction (14), where inventory of DCs is ignored. The range of distribution decision variables are defined by Restriction (35).

Procurement planning sub-model

According to the results of the first sub-model, the procurement model is responsible to plan about how much of what material from which supplier need to be purchased and how much inventory of them should be kept. The target is to minimize the total purchasing, ordering and raw material inventory costs.

Objective Function

$$\min: \sum_{f\in F}\left(\sum_{m\in M}\sum_{s\in S}\sum_{t\in T}\widetilde{purC}_{mst}.\,purQ_{msft}+\sum_{m\in M}\sum_{t\in T}\widetilde{hC}^{3}_{mf}.\,I^{2}_{mft}\right)+\sum_{m\in M}\sum_{s\in S}\sum_{t\in T}\widetilde{sC}^{2}_{mst}.\,y_{mst} \tag{36}$$

Subject to constraints (18) − (20) plus:

$$\sum_{m\in M}\sum_{f\in F} purQ_{msft} \le sCap_{st} \quad \forall s\in S,t \tag{37}$$

$$G.\,y_{mst} \le purQ_{msft} \quad \forall s\in S,m,f,t \tag{38}$$

$$\sum_{m\in M}\sum_{t\in T} purQ_{msft} \ge Qmin_{ms} \quad \forall s\in CS,f \tag{39}$$

$$purQ_{msft}, I^{2}_{mft} \ge 0 \text{ and } y_{smt}\in\{0,1\} \quad \forall s\in S,m,f,t \tag{40}$$

Restriction (37) is the modification of Constraints (21), where the purchased amount of raw materials is set in each manufacturing site, independently. Ordering cost in Restriction (38) is now applied to each factory, separately. Restriction (40) is the modification of Restriction (24), which includes procurement decision variables only.

The Fuzzy Decoupled Planning Model

This model states the non-integrated planning approach. Figure 7 illustrates the input and output decisions and information flow for all four planning sub-models. In this section, we just address the two sub-models of sales and production, not to repeat the distribution and procurement models, which have been described in PI-S&OP.

Sales planning sub-model

In decoupled planning, the sales decisions are being made based on cumulated orders, determined production cost of product, and the supply capacity of each factory, mostly by weight. The objective is to maximize the sales, according to the maximum determined supply capacity of each factory, in order to gain maximum profit. Cost reduction is the responsibility of local planning division of each site. The backlogged sale is inevitable and is addressed by production sub-model.

Objective Function

$$\max: \sum_{i\in I}\sum_{f\in F}\sum_{t\in T}\sum_{c\in C}\left(\widetilde{sP}_{ict}-\widetilde{epC}_{ift}\right).\,sQ_{icft} \tag{41}$$

Subject to following restrictions plus (SP3):

$$\sum_{f \in F} sQ_{icft} \geq dmin_{ict} \quad \forall c \in CC, i, t \tag{42}$$

$$\sum_{i \in I} \sum_{c \in C} sQ_{icft} \leq epCap_{ift} \quad \forall, m, t \tag{43}$$

$$sQ_{icft} \geq 0 \quad \forall c \in C, i, f, t \tag{44}$$

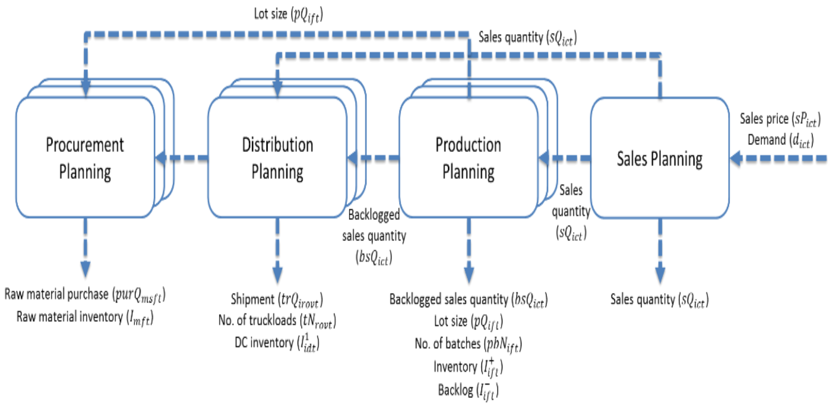

Fig. 7. Inputs and outputs of DP model

Production planning sub-model

According to the results of the sales planning sub-model, this model decides about the inventory levels, backorders/back sales and lot size. Due to dissociation of planning process in this approach, production decisions are made by the determination of capacity, thus, the backlogs would be inevitable. The production team has no effect on sales decisions and outsourcing is not possible. The target is to minimize the variable production cost, set-up, inventory holding, backlog, and lost sale cost.

Objective Function

$$\text{Min: } \sum_{i \in I} \sum_{t \in T} \left\{ \widetilde{pC}_{ift} . pQ_{ift} + \widetilde{sC}^1_{ift} . X_{ift} + \widetilde{hC}^1_{ift} . I^+_{ift} + \widetilde{boC}_{ift} . I^-_{ift} + \left(\sum_{c \in C} \widetilde{sP}_{icT} . bsQ_{icT} \right) \right\} \quad \forall f \tag{45}$$

Subject to restriction (SP4)-(SP6), (7)-(10) plus:

$$\sum_{f \in F} (pQ_{ift} + I^+_{ift-1} - I^-_{ift-1}) \geq \sum_{c \in CC} dmin_{ict} \quad \forall i, t \tag{46}$$

$$I^-_{ift} = I^-_{if0} \quad \forall i, f \tag{47}$$

$$bsQ_{icT}, pQ_{ift}, I^+_{ift}, I^-_{ift} \geq 0, pbN_{ift} \text{ is positive integer, and } X_{ift} \in \{0,1\} \quad \forall c \in C, i, f, t \tag{48}$$

Restriction (46) forces Restriction (42) to satisfy the contract demands to minimum committed amount. Restriction (47) modifies Restriction (11) through defining the opening backlog amount, where the closing backlog is out of control. The closing backlog is taken into account as lost sales and its penalty is considered in (45) as lost revenue. This penalty forces the lost sales to be in production capacity intervals. Restriction (48) is the positive restriction which is solely dedicated to production variables.

Solution Procedure

Now we have a model with fuzzy objective function and crisp restrictions. In this session, we first introduce the fuzzy arithmetic method to treat with the fuzzy objective function. Then, we describe, how we utilize the fuzzy arithmetic to defuzzify our objective function.

Fuzzy arithmetic

In this paper, as shown in Fig. 8, Triangular Fuzzy Numbers (TFNs) are used to present all operational costs. A TFN can be defined by three elements $\tilde{C} = (c^p, c^m, c^o)$ (Shahrasbi et al., 2017; Shermeh et al., 2016; Tarimoradi et al., 2015; Zarandi et al., 2015a, 2015b).

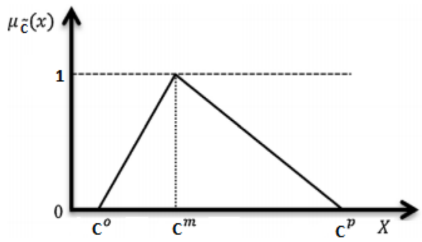

Fig. 8. A Triangular Fuzzy Numbers (TFNs).

In this paper, we used the TFNs for its simplicity of computation, comparing to other fuzzy numbers, as presented in Equation (49) (Alavidoost et al., 2015b; Alavidoost et al., 2014; Alavidoost, 2017):

$$\begin{aligned}
&\tilde{X} + \tilde{Y} = (X_1 + Y_1, X_2 + Y_2, X_3 + Y_3)\\
&\tilde{X} - \tilde{Y} = (X_1 - Y_3, X_2 - Y_2, X_3 - Y_1)\\
&\tilde{X} \times \tilde{Y} = (X_1 \times Y_1, X_2 \times Y_2, X_3 \times Y_3)\\
&\tilde{X}/\tilde{Y} = (X_1/Y_3, X_2/Y_2, X_3/Y_1)
\end{aligned} \tag{49}$$

For difuzzification of TFNs, we use Equation (50) as following:

$$\text{Defuzzification}(\tilde{A}) = \frac{(A_1 + 2 \times A_2 + A_3)}{4} \tag{50}$$

Difuzzification of the model

The objective function consists of the summation of different TFNs. So, according to the Equation (49), the objective function itself, should be a TFN and can defuzzify it by Equation (50). Hence, the objective Functions (1), (25), (34), (36), (41), and (45) will be converted into (51)-(56), respectively.

$$\begin{aligned}
\tilde{F} = \max(\widetilde{TP}) = \max \Bigg(& \sum_{i\in I}\sum_{c\in C}\sum_{t\in T}\frac{1}{4}\left(sP^{o}_{ict} + 2\cdot sP^{m}_{ict} + sP^{p}_{ict}\right). sQ_{ict} \\
& - \Bigg\{\sum_{i\in I}\sum_{f\in F}\sum_{t\in T}\frac{1}{4}\Big(\left(pC^{o}_{ift} + 2\cdot pC^{m}_{ift} + pC^{p}_{ift}\right)\cdot pQ_{ift} \\
& + \left(sC^{o1}_{ift} + 2\cdot sC^{m1}_{ift} + sC^{p1}_{ift}\right). X_{ift} \\
& + \left(hC^{o1}_{if} + 2\cdot hC^{m1}_{if} + hC^{p1}_{if}\right). I^{+}_{ift} \\
& + \left(boC^{o}_{ift} + 2\cdot boC^{m}_{ift} + boC^{p}_{ift}\right). I^{-}_{ift}\Big)\Bigg\} \\
& - \Bigg\{\sum_{i\in I}\sum_{r\in R_{f,d}\cup R_{f,c}\cup R_{d,c}}\sum_{o\in O}\sum_{v\in V}\sum_{t\in T}\frac{1}{4}\Big(\big(tvC^{o}_{irov} + 2\cdot tvC^{m}_{irov} \\
& + tvC^{p}_{irov}\big). trQ_{irovt} + \left(tfC^{o}_{rov} + 2\cdot tfC^{m}_{rov} + tfC^{p}_{rov}\right). tN_{rovt}\Big) \\
& + \sum_{i\in I}\sum_{r\in R_{f,d}}\sum_{o\in O}\sum_{v\in V}\sum_{t\in T}\frac{1}{4}\Big(\left(trC^{o}_{ir} + 2\cdot trC^{m}_{ir} + trC^{p}_{ir}\right). trQ_{irovt}\Big) \\
& + \sum_{i\in I}\sum_{d\in D}\sum_{t\in T}\frac{1}{4}\Big(\left(hC^{o2}_{id} + 2\cdot hC^{m2}_{id} + hC^{p2}_{id}\right). I^{1}_{idt}\Big)\Bigg\} \\
& - \Bigg\{\sum_{m\in M}\sum_{s\in S}\sum_{f\in F}\sum_{t\in T}\frac{1}{4}\Big(\big(purC^{o}_{mst} + 2\cdot purC^{m}_{mst} \\
& + purC^{p}_{mst}\big). purQ_{msft}\Big) \\
& + \sum_{m\in M}\sum_{s\in S}\sum_{t\in T}\frac{1}{4}\Big(\left(sC^{o}_{mst} + 2\cdot sC^{m}_{mst} + sC^{p}_{mst}\right). y_{mst}\Big) \\
& + \sum_{m\in M}\sum_{f\in F}\sum_{t\in T}\frac{1}{4}\Big(\left(hC^{o3}_{mf} + 2\cdot hC^{m3}_{mf} + hC^{p3}_{mf}\right). I_{mft}\Big)\Bigg\}\Bigg)
\end{aligned} \tag{51}$$

$$\text{Max: } \sum_{i\in I}\sum_{f\in F}\sum_{t\in T}\frac{1}{4}\Bigg\{\Big(\sum_{c\in C}\big(sP^{o}_{ict}+2\cdot sP^{m}_{ict}+sP^{p}_{ict}\big).\,sQ_{icft} \\ -\big(pC^{o}_{ift}+2\cdot pC^{m}_{ift}+pC^{p}_{ift}\big).\,pQ_{ift} \\ -\big(sC^{o1}_{ift}+2\cdot sC^{m1}_{ift}+sC^{p1}_{ift}\big).\,X_{ift} \\ -\big(hC^{o1}_{if}+2\cdot hC^{m1}_{if}+hC^{p1}_{if}\big).\,I^{+}_{ift} \\ -\big(boC^{o}_{ift}+2\cdot boC^{m}_{ift}+boC^{p}_{ift}\big).\,I^{-}_{ift}\Big)\Bigg\} \tag{52}$$

$$\text{Min: } \sum_{f\in F}\sum_{o\in O}\sum_{i\in I}\sum_{v\in V}\sum_{t\in T}\frac{1}{4}\Bigg\{\sum_{r\in R}\Big(\big(tvC^{o}_{irov}+2\cdot tvC^{m}_{irov}+tvC^{p}_{irov}\big).\,trQ_{irovt} \\ +\big(tfC^{o}_{rov}+2\cdot tfC^{m}_{rov}+tfC^{p}_{rov}\big).\,tN_{rovt}\Big) \\ +\sum_{r\in R_{f,d}}\big(trC^{o}_{ir}+2\cdot trC^{m}_{ir}+trC^{p}_{ir}\big).\,trQ_{irovt}\Bigg\} \tag{53}$$

$$\text{min: } \sum_{f\in F}\frac{1}{4}\Bigg\{\sum_{m\in M}\sum_{s\in S}\sum_{t\in T}\big(purC^{o}_{mst}+2\cdot purC^{m}_{mst}+purC^{p}_{mst}\big).\,purQ_{msft} \\ +\sum_{m\in M}\sum_{t\in T}\big(hC^{o3}_{mf}+2\cdot hC^{m3}_{mf}+hC^{p3}_{mf}\big).\,I^{2}_{mft}\Bigg\} \\ +\sum_{m\in M}\sum_{s\in S}\frac{1}{4}\sum_{t\in T}\big(sC^{o}_{mst}+2\cdot sC^{m}_{mst}+sC^{p}_{mst}\big).\,y_{mst} \tag{54}$$

$$\text{max: } \sum_{i\in I}\sum_{f\in F}\sum_{t\in T}\frac{1}{4}\sum_{c\in C}\Big\{\big(sP^{o}_{ict}+2\cdot sP^{m}_{ict}+sP^{p}_{ict}\big) \\ -\big(epC^{o}_{ift}+2\cdot epC^{m}_{ift}+epC^{p}_{ift}\big)\Big\}.\,sQ_{icft} \tag{55}$$

$$\text{Min: } \textstyle\sum_{i\in I}\frac{1}{4}\sum_{t\in T}\Big\{\big(pC^{o}_{ift}+2\cdot pC^{m}_{ift}+pC^{p}_{ift}\big).\,pQ_{ift}+\big(sC^{o1}_{ift}+2\cdot sC^{m1}_{ift}+ \\ sC^{p1}_{ift}\big).\,X_{ift}+\big(hC^{o1}_{if}+2\cdot hC^{m1}_{if}+hC^{p1}_{if}\big).\,I^{+}_{ift}+\big(boC^{o}_{ift}+2\cdot boC^{m}_{ift}+ \\ boC^{p}_{ift}\big).\,I^{-}_{ift}+\big(\textstyle\sum_{c\in C}\big(sP^{o}_{ict}+2\cdot sP^{m}_{ict}+sP^{p}_{ict}\big).\,bsQ_{icT}\big)\Big\} \tag{56}$$

Results

Case Description

For the single-site environment, the PI-S&OP model acts according to the framework, depicted in Fig. 2. In fact, this model can be considered as a specific model of the multi-site fully integrated planning, which the enterprise has only one factory F. As depicted in

Figure 2 the cumulated demand and the decision variable are defined for one factory. Based on the same logic, the PI-S&OP and DP models are developed for single-site and site specific demand (Fig. 2 & 7). Further layers' planning as production, distribution, and procurement, now should be single layer, illustrating a single site planning process.

Data Gathering

Due to the massive size of the problem, data gathering from all the functional divisions was were an extremely challenging job to do. The needed data of each division were maintained by the division itself, mostly on MS Excel format. The collection of needed data, both the soft and hard versions on paper, was performed through interviewing managers or supervisors of each department and persuading them to support the study. One of the challenges through gathering and preparing needed data was the inconsistency of the same data, gathered from different departments. The other problem was the unavailability or confidentiality of some R&D, sales, and financial data.

The original customer demand is registered and documented by the company. In this organization, the contract and non-contract data are entered, on daily basis. Most of the products are produced through MTS manufacturing basis. Taking into account the two days of preparation and logistics lead time, the actual customer demand has to be registered, at least two days before delivering it, although the cumulative production lead time is much more for some products. Figure 9 depicts that the monthly customer demands are pretty seasonal.

Although the backlog is possible in the company, since today, there was no estimation for that. Expressing the negative effect of backorder and the related inventory, and to make sure about applying this negative impact in our mathematical model, a backlogged sales cost was needed to be calculated. In practice, this cost should reflect any tangible and intangible effect on customer's perception from the organization's service standard. To determine this cost in our study, we multiplied the current lost sale in average weighted sales price of each product category. However, in the sensitivity analysis section, we find out that increasing this number will not have significant effect on backlog amount. In order to organize the vast amount of gathered data and to facilitate accessibility to it, we developed a database in MS Excel.

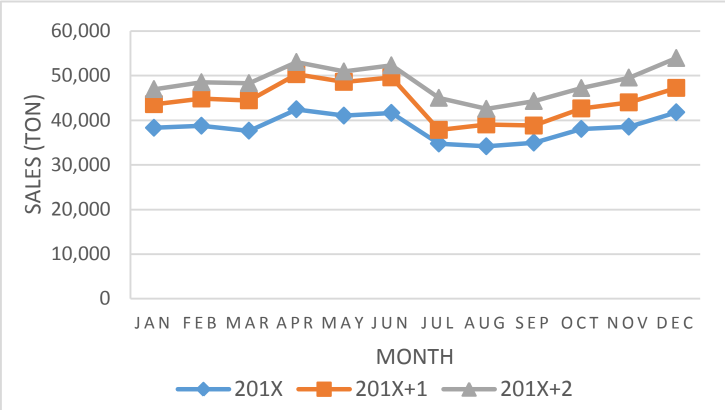

Fig. 9. Monthly sales data of the dairy company in three years

Experimental Design

For quantitative analysis, the validity of all three models of FI-S&OP, PI-S&OP, and decoupled models have been tested using system's actual information of last year. Performance measures consist of total supply chain profit service level, revenue, capacity utilization, and cost are calculated in all models. The advantages of FI-S&OP over the other two is revealed in the results comparison phase. After the comparison phase, a sensitivity analysis is carried out, where a number of KPI's are measured and compared in five different levels (Table), level 0% demonstrate the basic level of the parameter, and the 10% and 20% show the decrease or increase in the related parameter, respectively.

Table 1. The test program for sensitivity analys

Factors	Levels				
Unit market price (%)	-20	-10	0	10	20
Demand (%)	-20	-10	0	10	20
Unit production cost (%)	-20	-10	0	10	20
Unit shipping cost (%)	-20	-10	0	10	20
Unit raw material purchase cost (%)	-20	-10	0	10	20
Unit raw material inventory cost (%)	-20	-10	0	10	20

Model Validation

The results in Table 2 show that all the three models yield satisfying answers for functional areas and the results are pretty near to the factory nominal capacity and orders amount. Close to 100% of the sales/demand ratio supports this claim as well. Little difference between the sales amounts of three models is due to the different approaches in planning. The conceptual analysis of the study beside the financial application is addressed in next session. Finally, the capacity utilization in all the three models is around 70%, which indicates that 30% of the capacity is idle. This is aligned with the company's policy to reserve this amount for machine breakdowns. All the results prove the validity of our models.

Table 2. Volume-based validation result

Item	DP Model	PI-S&OP Model	FI-S&OP Model
Nominal capacity (Ton)	194,400,000	194,400,000	194,400,000
Actual demand quantity 201X (Ton)	145,309,607	145,309,607	145,309,607
Total sales quantity by model (Ton)	133,035,863	130,987,521	130,987,521
Total production quantity by model (Ton)	120,253,256	125,546,856	125,546,856
Total shipment quantity by model (Ton)	119,568,985	122,235,658	122,235,658
Sales/demand (%)	91.6%	90.1%	90.1%
Capacity utilization (%)	61.9%	64.6%	64.6%

Benefit Evaluation

The advantages regarding the measurement of the FI-S&OP over PI-S&OP and DP models are performed through these KPI's: total cost, total revenue, total profit, capacity utilization and customer service level. Table 3 3 presents the advantages of FI-S&OP model over the other two, in both Islamic Republic Rials (IRR) and percentage. As we could guess, the FI-S&OP model obtains the greatest total profit for the organization. Better total annual profit of FI-S&OP model over the DP model is justified through the more optimized sales decisions of the former one. High standard deviation between total revenue and total cost reflects the fact that in PI-S&OP approach, through increasing the sales and production amount along with gaining more profit, more procurement and distribution costs are imposed to the system.

Table 3. The advantages of the FI-S&OP over less integrated approaches

Item	Revenue	Total Cost	Profit	Service level	Capacity utilization
Benefit over DP (IRR)	120,023,348,923	-53,625,326	120,076,974,249	-	-
Benefit over DP (%)	1.9%	-1.0%	7.1%	-1.1%	1.9%
Benefit over SP-S&OP (IRR)	17,032,265	-6,159,836	23,192,101	-	-
Benefit over SP-S&OP (%)	0.2%	-0.1%	1%	-	-

The advantages of the fully integrated over the partially integrated model are not that much outstanding, because of the integration of sales and production decisions in both. As can be seen in Table 3, most of the difference is due to cost reductions, rather than profit increase. The reduced profit in fully integrated model is because of the more constraints applied to the model, which leads to more reductions in initial sales plan.

Sensitivity Analysis

The advantages of the FI-S&OP model over DP are completely intense, while the superiority of the model over the PI-S&OP model is gentler. As described before, the advantages of FI-S&OP model is majorly related to the growth in revenue or decrease in costs. The savings in transportation cost from integrated sales and distribution planning were reported in numerous studies before (Chandra & Fisher, 1994; Fumero & Vercellis, 1999).

As shown in Figure 11-14, the advantages of FI-S&OP model change with the different market prices and operational costs. The market price shows the biggest influence on the advantages of FI-S&OP over the other two models, especially when the prices decrease (Fig. 11). When market price decreases, sales profit will be reduced. Demand is another factor affecting the advantages of FI-S&OP model. However, the advantages are limited over the DP model. As depicted in Figure 13, the slight increase in advantages is due to the joint sales and production decisions of FI-S&OP and PI-S&OP models, leading to accept more demands and bringing higher cost and revenue for the supply chain, consequently.

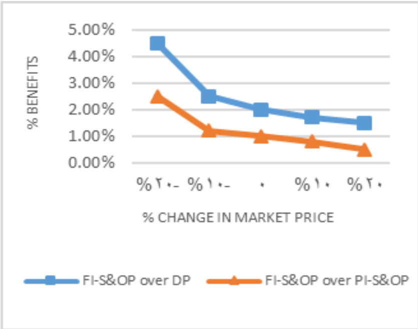

Fig. 10. The impact of the demand on the advantages of FI-S&OP

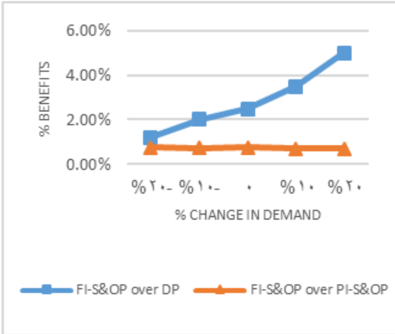

Fig. 11. The impact of the raw material price on the advantages of FI-S&OP

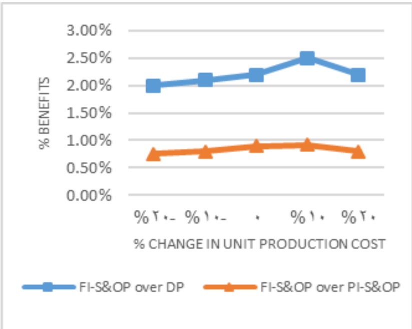

Fig. 12. The impact of the production cost on the advantages of FI-S&OP

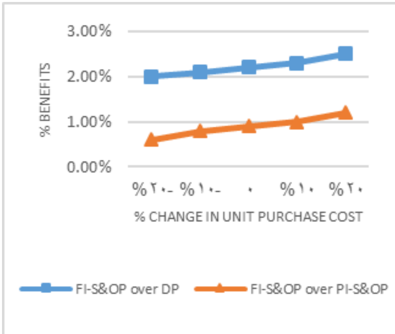

Fig. 13. The impact of different market prices on the advantages of FI-S&OP

Comparing with the first two parameters, cost has less influence on the advantages of FI-S&OP model. As shown in the Figure 10, when production cost per unit increases, the advantages of FI-S&OP model over DP will increase slightly. This is because of the improved sales decision of the former. As expected, the unit shipping cost will affect the advantages of FI-S&OP model over PI-S&OP (Fig. 14), since the distribution planning is not integrated in the latter. We may expect these advantages over DP model, as well. While the FI-S&OP model seeks different solutions to optimize profit, when the unit shipping cost starts to increase, the total profit of the model will decrease. Along with the increase in raw material price, the advantages of FI-S&OP model over PI-S&OP and DP will increase. Eventually, as depicted in Figure 15, the advantages of FI-S&OP model over the other two show less sensitivity to the raw material inventory holding cost.

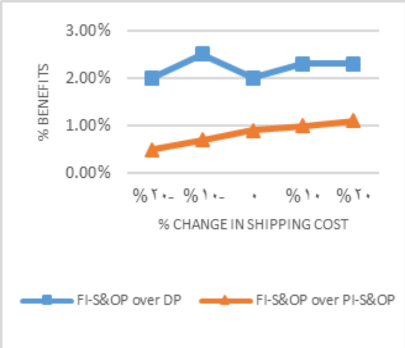

Fig. 14. The impact of the shipping cost on the advantages of FI-S&OP

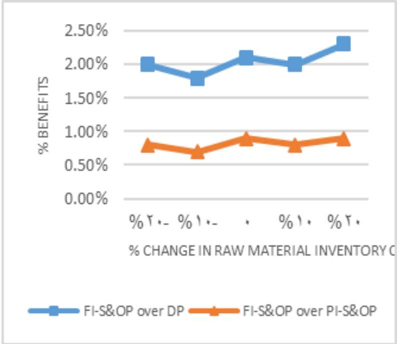

Fig. 15. The impact of the raw material inventory on the advantages of FI-S&OP

Conclusion and Suggestions for Future Researches

In this study, we investigated two different S&OP approaches, a fully integrated S&OP (FI-S&OP) approach which integrates all supply chain planning functions, and a partially integrated S&OP (PI-S&OP) with joint sales and production decisions and isolated local distribution and procurement decisions. Then, we developed mathematical models to evaluate the added value of the approaches in a multi-site forming company, where backorder was allowed. Also, a DP approach was developed to demonstrate the traditional planning condition. Then, we evaluated the models, using real data, through a case study in dairy manufacturing industry. The sensitivity analysis results show the absolute superiority of the FI-S&OP approach over the PI-S&OP and DP approaches in all situations, especially in the violation of demand and market price.

The mathematical models of this study were developed through the MTS logic. Thus, there will be possibility to present FI-S&OP model in Make-to-Order (MTO) environment. In real world, at mid-term planning stage, the production planning of MTS and MTO environments is being made using forecasts. Therefore, the other suggestion of this study can be the investigation of the effect of the demand forecast error on FI-S&OP advantages over the PI-S&OP and DP models in stable demand circumstances. Also, the dynamic pricing could be addressed in S&OP in another study.

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