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Planning Collaboration among Multiple Production Facilities: A Web-based Strategy

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Abstract: In order to gain competitive advantage in the globalization today, effective management strategies need to be incorporated, especially in collaborating information sharing among multi-site manufacturing facilities. Information visibility within the supply chain is the process of sharing critical data required to manage the flow of products, services and information in real time between suppliers and customers. If the information is available but cannot be accessed by the parties most able to react to a given situation, its value degrades drastically. We propose a software system, which incorporates mathematical models, user-interface and web application to solve the collaborative planning problems between multiple sites. Model validations proved the architecture to be robust and suggested cost savings through priority goal structuring. This study offers a practical solution to real-life industrial problems often faced by the management of manufacturing industry in the world today.

Key words: Strategy, information technology, planning, architecture, decision-making

INTRODUCTION

In order to produce cost-effective products within the time scales requested by the customers, many manufacturing enterprises are therefore becoming global businesses covering multiple manufacturing sites. Effective management strategies need to be incorporated in order to gain competitive advantage, especially in collaborating information sharing among multi-site manufacturing facilities.

This study proposes the development of a prototype software system as an approach to collaborate decision-making between two facilities and introducing information visibility into the supply chain. Mathematical models were developed, which are able to generate optimal planning solutions that consider production, inventory, backorder and sub-contracting levels for the planning horizon. The generated up-to-date plans and schedules becomes a valuable set of information to the testing-distribution facility and are propagated through the Internet by a web application.

Related works on multi-site production planning: The collaboration of multi-site manufacturing enterprises in decision-making has been the topic of discussion recently in the area of supply chain management. Although there are many literature on how to manage or optimize the overall supply chain (from one end of the suppliers to the other end of the customers), there are still no comprehensive literature in specific, on how to facilitate the production planning of a multi-site environment. Production planning is a classical problem in operations research. Basically, there are approaches to the production planning problems in the industry. A monolithic approach in which the problem is solved in one level for the entire horizon and Hierarchical Production Planning (HPP) in which decision-making domain is partitioned into hierarchical levels in agreement with today's organizational structure of companies

A rigorous mathematical analysis of HPP is found in the pioneering work of Hax and Meal[1] and Gabbay[2]. Theoretical work on the topic has followed[3-8]. All of these research contributions confirm that the HPP by itself is not a detailed prescription on how to make decisions or to structure specific level but rather it is an approach that lends itself to present the hierarchy of decisions that exist in almost every industrial and service organization.

Bullinger *et al.*[9] proposed an object-oriented model to project the multi-site production within the operative scope of production planning. They developed a generic work plan model of a production process in multi-site production in the area of automobile-manufacturing industry. The production process within the organization and its information system were well captured using notations of Coad and Yourdon[10]. However, this study did not elaborate on the mathematical formulations used to optimize production planning nor suggest any means to communicate with the multi-site partners.

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A hierarchical decision support system for production planning was proposed by Özdamar *et al.*[11] to enable production planners to utilize complex and structured planning algorithms interactively with a dialogue management system. The user-interface hides the theoretical background of the model base consisting of multi-operational aggregate planning models and disaggregation algorithms used at the family and end item planning levels. The model base consists of a four-level hierarchy involving aggregate planning (product type planning level), family disaggregation, end item disaggregation and Master Production Schedule (MPS). Linear Programming (LP) was used to formulate the aggregate product type level while constructive heuristic was used for the MPS. They provided the user with modeling options at the APP level, to include subcontracting, backorders, safety stocks, etc. At the MPS level, the system allows the user to make changes in both the quantities and sequence of the end item production runs. However, the algorithm formulated does not allow the user to consider multiple and sometimes conflicting goals/objectives. In their study, the generated production plans was only made available within the enterprise and thus, is not suitable to address the multi-site environment.

Even though there is a considerable number of research works carried out by other researchers addressing the multi-site production-planning problem, the authors are unaware of any literature that addresses the specific scope and objectives of this research. Ofcourse, each problem is specific and unique from the other problems. However, majority of the research papers are based on the application of the Internet to collaborate product designs, virtual manufacturing (which involves outsourcing) and also e-Enterprise Resource Planning (e-ERP), which is not the intention of this research area.

The manufacturing collaboration environment: The manufacturing collaboration deals two facilities. The research area however, does not include the whole organizations along a typical supply chain. The identified research problem is more specific and considers the manufacturing sector involving two facilities. The raw materials supplier and the transportation activities have been excluded in this research.

This study addresses the coordination of planning decisions between an assembly facility (F1) and a testing-distribution facility (F2). Both facilities are separated by geographical boundaries, but connected by dependency of planning decisions. F2 may be described as a customer service and distribution facility where the finished products demand estimates are received from their regular customers. The demand estimates presents the product quantities and types required for the next three months' time horizon. These estimates are then forwarded to F1. At F1 the planning and scheduling decisions are prepared based on the demand received from F2. These decisions include production, backorders, sub-contracting and manpower levels for both mid term horizon (12 weeks) and presented by Aggregate Production Planning (APP) and short-term horizon (three weeks) presented by MPS.

Finished products are initially tested for quality, prior to dispatching to F2. A final quality testing activity will take place at F2 before finally, dispatching the end products to the customers. Figure 1 describes the flow of information and products between the facilities. Although the planning and scheduling decisions are generated for product families (three months) and individual items (one month), booked orders are subject to variations each week. The organization simply cannot adopt a policy of freezing the planning and scheduling decisions. Therefore, the management allows orders variations (cancellation /additions) in order to maintain high level of customer services.

The assembly facility (F1) operates on three shifts per day and consists of two assembly lines. Thirty six end products are divided into 10 product families; six families are produced in assembly line 1 and four families in assembly line 2. As for the production and scheduling process, F1 starts by developing APP that deals with the product families and focuses on mid-term planning (12 weeks). Decision required at this level of planning includes production, backorder, sub-contracting and manpower levels. Then these decisions are disaggregated into a MPS that focuses on short-term planning horizon (three weeks).

In order to provide efficient customer services while maximizing production and minimizing costs, the manufacturing system has to be dynamic to generate a faster and more effective response. Nevertheless, this is no exception for F2 as a customer service and distribution facility. F2 experiences order cancellations/additions which occurs too often from customers. When order cancellations/additions occur, F2 needs to inform F1 of the changes immediately so that F1 can re-generate their production plans reflecting the new order changes. This requires a form of system to enable F2 to commute newly updated demand estimates to F1.

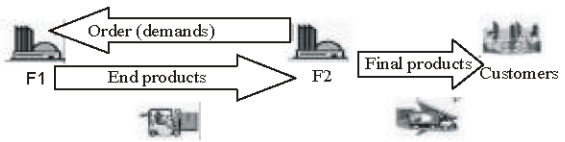

Fig. 1: Information flow between F1 and F2

This collaboration problem could be solved entirely if the manager at F2 could have the opportunity to access the updated production plans generated by F1 through the means of information technology such as the Internet. By viewing the plans, the manager at F2 could have a broader view of F1's capability in meeting their targets and anticipate changes if any. Therefore, the author believes that a system could be proposed to enhance the collaboration between F1 and F2, so that both sides of the facility management can be involved in the decision-making.

THE PROTOTYPE SYSTEM

Based on the research problem, a prototype system is proposed to aid the decision-making process. The proposed system needs to provide the following functionalities:

Generate feasible optimal solutions: The prototype must be able to provide an optimal solution to the production planning problem, whenever possible. The F1 management must generate APP and then MPS for its assembly facility every week. The decision variables to be determined in the planning include production, backorder, sub-contracting and manpower for both regular and overtime levels with the objective of minimizing total cost.

Provide a user-friendly GUI interface: The end-user (F1 management)-system main interaction interface must be able to display the correct information based on the generated APP and MPS. The interface must be simple yet provides a clear set of functionalities to aid the user in generating APP and MPS.

Provide a consistent and up-to-date view of generated plans across facilities: Management at F2 must be able to access and view the generated APP and MPS of F1 through the Internet, whenever any weekly revisions occur in plans at F1. The information displayed must be updated, with a simple interface.

Integrate the different components to form a whole system: The proposed architecture must be able to integrate the plans developed by ILOG OPL Studio/CPLEX with input data in Excel spreadsheets, the user-interface to display generated results to the end-user and the web application to display up-to-date plans through the Internet.

Multi-site collaboration software system (MUSICOS): Given all the requirements in the earlier section, an analysis is performed to determine the design of the prototype. According to the requirements, there are two problems which need to be solved. The first problem is to solve a production planning and scheduling at the assembly facility, F1, while the second problem is to share information of the production plans with the testing-distribution facility, F2. Therefore, the Multi-site Collaboration Software System (MUSICOS) shall consist of two components to address the two problems. The first component is called the Production Planning and Scheduling System (PPS). The second component, which is called WEB, forms the web-based solution to information sharing from F1 to F2.

Figure 2 shows the overview of architecture of the planning system and it also displays how MUSICO would fit in the described research environment. The architectural style of the prototype is a client-server type. Facility 2 (F2) represents the client-side, while Facility 1 (F1) is the server. In the Server-side, the PPS comprise of the user-interface and ILOG Suite (OPL Studio and CPLEX as the optimization engine) and retrieves and stores data from the Excel spreadsheets. The web-based application (WEB) publishes the APP and MPS results onto the Microsoft's Personal Web Server (PWS) where it is made available via the Internet for the viewing of F2. Then we present the mathematical models and it worth noting that these developed models are based on enhancement of Heah and Omar[12].

Planning at the product family level (APP): This is the highest level of production planning in our research environment. Production decisions at this level provide targets for the MPS. The APP is concerned with finding optimal aggregate Production, inventory, backorder levels and size of the manpower necessary to respond to the future demand on product families level. The planning horizon for this model is 12 weeks. The APP model was formulated as a LP model.

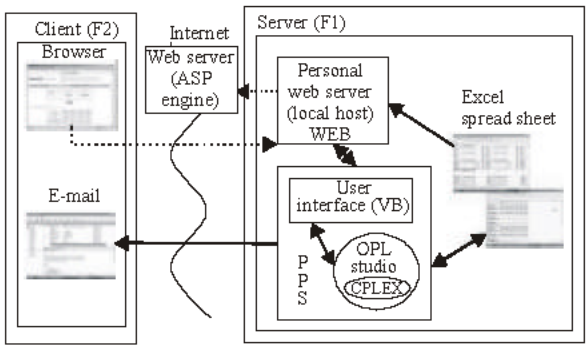

Fig. 2: Overview architecture of the system

Both The APP and MPS were developed using OPL Studio 3.5 modeling language and the CPLEX 7.1 solver.

Decision Variables:

P_{it} = Production level of product family I (units) during period t.
E_{it} = Inventory level of product family I at the end of period t.
B_{it} = Backorder of product family I at the end of period t.
S_{it} = Subcontracted production quantity of product family I in period t.
R_t = Regular time to be used during period t.
O_t = Over time hours to be used during period t.

Parameters:

Cp_{it} = Unit production cost for product family I (per unit) during period t (excluding labor).
Ci_{it} = Unit inventory holding cost (per unit, per period) for product family I during period t.
Cb_{it} = Unit backorder cost for product family I in period t.
Cs_{it} = Unit subcontracting cost for product family I in period t.
Mr_{it} = Regular time manpower cost (per man-hour) in period t.
Mo_{it} = Over time manpower cost (per man-hour) in period t.
D_{it} = Demand estimates for product family I during period t.
m_i = Manpower (man hours) required to produce per unit of product family i.
$(TR)_t$ = Total regular time (hours) available in period t.
$(TO)_t$ = Total over time (hours) available in period t.
Q_t = Capacity available during period t.

Objective Function: Minimize the sum of production cost, inventory cost and workforce time cost.

$$\text{Min.} \sum_{i=1}^{N}\sum_{t=1}^{T}[(Cp_{it}\,P_{it} + Ci_{it}E_{it}) + Cb_{it}B_{it} + Cs_{it}S_{it}] + \sum_{t=1}^{T}(Mr_tR_t + Mo_tO_t) \quad (1)$$

Subject to

$$S_{it} + P_{it} + E_{it-1} - B_{it-1} - E_{it} + B_{it} = D_{it} \qquad \forall i,t \quad (2)$$

$$\sum_{i=1}^{N} P_{it} \le Q_t \qquad \forall t \quad (3)$$

$$\sum_{i=1}^{N}\sum_{t=1}^{T} B_{it} = 0 \qquad \forall i,t \quad (4)$$

$$\sum_{i=1}^{N} m_i P_{it} \le R_t + O_t \qquad \forall t \quad (5)$$

$$R_t \le (TR)_t \qquad \forall t \quad (6)$$

$$O_t \le (TO)_t \qquad \forall t \quad (7)$$

$$P_{it}, E_{it}, R_t, O_t \ge 0 \qquad \forall i,t \quad (8)$$

In the above formulation, Eq. 1 represents the objective function, which is to minimize the sum of production, inventory, backordering, subcontracting and workforce (regular and overtime) costs. Equation 2 is the material balance, stating that the demand, inventory, backorders and subcontracting relationship. Equation 3 states the capacity limitations and Eq. 4 enforces backorders to be zero at the end of the planning horizon. Equation 5 states the workforce balance ensuring that the labor capacity for each period is sufficient for production level. Equation 6 and 7 present the limitations on both regular and overtime levels for each planning period. Equation 8 presents the nonegativity constraint.

Planning at the end item level (MPS): Production decisions at this level are constrained by the decisions made at the upper level. The MPS disaggregates aggregate decisions into final decisions and deals with product items. The modeling at this level of planning takes into account the presence of multiple goals and therefore, it is formulated as linear pre-emptive goal programming. The model requires information on:

- Weekly demand estimates of end items;
- Output values from APP;
- Capacity available;
- Beginning backorder levels of end items and
- Number of man-hour required producing one unit of each end item.

The decision variables, parameters and mathematical formulation are presented next.

Decision Variables:

P_{kit} = Number of units of item k of product family i to be produced in period t.
E_{kit} = Number of units of inventory of item k of product family i in the end period t.
B_{kit} = Backorder of product family i at the end of period t.
S_{kit} = Subcontracted production quantity of product family i in period t.
$(d_1^+)_{it}$ = Over production of product family i in period t.
$(d_1^-)_{it}$ = Under production of product family i in period t.
$(d_2^+)_{it}$ = Over achievement of the desired aggregate inventory level of product family i in period t.

$(d_2^-)_{it}$ = Under achievement of the desired aggregate inventory level of product family i in period t.
$(d_3^+)_{it}$ = Positive deviation of the desired aggregate backorder level of product family i in period t.
$(d_3^-)_{it}$ = Negative deviation of desired aggregate backorder level of product family i in period t.
$(d_4^+)_{it}$ = Positive deviation of the desired aggregate sub-contracting level of product family i in period t.
$(d_4^-)_{it}$ = Negative deviation of the desired aggregate sub-contracting level of product family i in period t.
$(d_5^+)_{it}$ = Under utilization of over time available in period t.
$(d_5^-)_{it}$ = Over time available in period t.
U_t = Under-time used in period t.
O_t = Over time used in period t.

Parameters:

$(DA)_{it}$ = Desired aggregate production for product family i in period t.
$(DE)_{it}$ = Desired aggregate inventory level for product family i in end of period t.
B_{it} = Desired aggregate backorder level for product family i in end of period t.
S_{it} = Desired aggregate sub-contracting level for product family i in end of period t.
m_{kit} = Number of man-hour required to produce one unit of item k of product family i in period t.
$(TR)_t$ = The planned regular time available in period t.
$(TO)_t$ = The planned over time available in period t.
Q_t = Capacity available in period t.
D_{kit} = Demand for item k of product family i in period t.

$$\text{Min. } W1\sum_{i=1}^{N}\sum_{t=1}^{T}(d_1^+)_{it} + W2\sum_{i=1}^{N}\sum_{t=1}^{T}(d_2^-)_{it} + W3\sum_{i=1}^{N}\sum_{t=1}^{T}(d_3^+)_{it} + W4\sum_{i=1}^{N}\sum_{t=1}^{T}(d_4^+)_{it} + W5\sum_{i=1}^{T}(d_5^+)_t \quad (9)$$

Subject to:
Goal constraints:

for i=1,2,3,…,N; t=1,2,…,T;

Aggregate Production Requirement:

$$\sum_{k=1}^{K}P_{kit} + (d_1^-)_{it} - (d_1^+)_{it} = (DA)_{it} \quad (10)$$

Aggregate Inventory Requirement:

$$\sum_{k=1}^{K}E_{kit} + (d_2^-)_{it} - (d_2^+)_{it} = (DE)_{it} \quad (11)$$

Aggregate Backorder Requirement:

$$\sum_{k=1}^{K}B_{kit} + (d_3^-)_{it} - (d_3^+)_{it} = B_{it} \quad (12)$$

Aggregate Sub-contracting Requirement:

$$\sum_{k=1}^{K}S_{kit} + (d_4^-)_{it} - (d_4^+)_{it} = S_{it} \quad (13)$$

System constraints:

$$S_{kit} + P_{kit} + E_{kit-1} - B_{kit-1} - E_{kit} + B_{kit} = D_{kit} \quad (14)$$

$$\sum_{k=1}^{K}\sum_{i=1}^{N}P_{kit} \le Q_t \quad (15)$$

$$\sum_{i=1}^{N}\sum_{k=1}^{K}m_{kit}P_{kit} + U_t - O_t = (TR)_t \quad (16)$$

$$O_t + (d_5^-)_t - (d_5^+) = (TO)_t \quad (17)$$

$$P_{kit}, E_{kit}, O_t, (d_1^+)_{it}, (d_1^-)_{it}, (d_2^+)_{it}, (d_2^-)_{it}, (d_3^+)_{it}, (d_3^-)_{it}, (d_4^+)_{it}, (d_4^-)_{it}, \ldots\ldots (d_5^-)_t, (d_5^+)_t \ge 0 \quad (18)$$

Equation 9 gives the objective function that aims to minimize the excess of production, inventory, backorder and subcontracting levels as well as minimizing the under utilization of overtime available at each planning period. The relative importance of the goals is addressed by assigned weights W_1, W_2, W_3 and W_4 in each goal in the objective function. Equation 10-13 give the goal constraints representing aggregate production, inventory, backorder and subcontracting target levels. Equation 14-17 defined the system constraints and representing material balance, capacity limitations and workforce balance. Equation 18 is the nonegativity constraint.

The user-interface of PPS: The model base (ILOG OPL Studio) communicates with the user through a graphical user-interface to activate the necessary models (APP/MPS) and modeling options such as backorder and sub-contracting. The user-interface is designed with Visual Basic 6.0. The input data are retrieved and the results are stored in Excel spreadsheets.

Two modules are developed for each of the planning levels; APP and MPS. The objective of the user-interface is to shield the user from the complex mathematical models and creating a systematic approach to generate the APP and MPS, with a click of a button. The interface warns the user if any infeasible solutions occur while generating the APP. Upon infeasibility, the interface also disallows continuation of the next step, which is to generate the MPS. The activity diagram as shown in Fig. 3 shows the user activities during the course of generating APP/MPS using the user-interface.

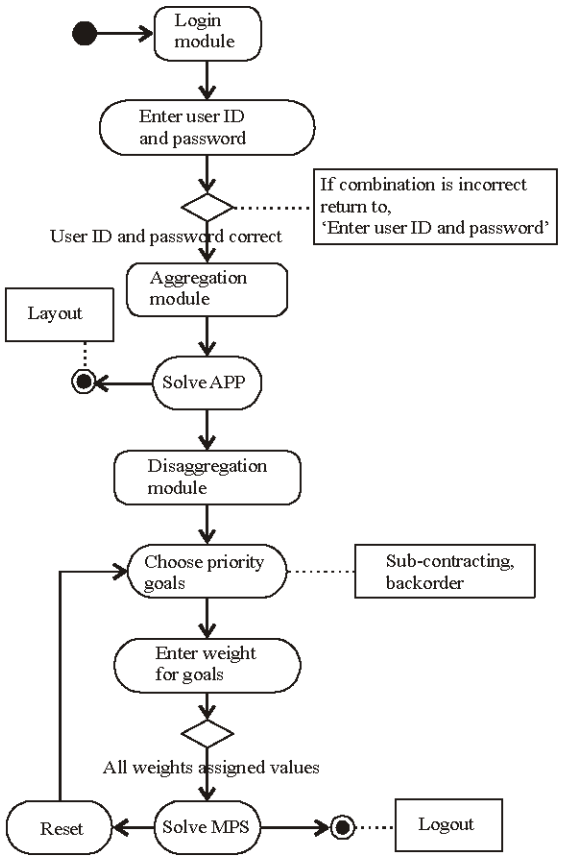

Fig. 3: Steps in generating APP/MPS

Aggregate module: The generated APP is conveyed to the user in a tabular form, so that decision variables such as production, inventory and backorder/sub-contracting levels over the whole planning horizon can easily be observed. It can be seen form Figure 4 that executing the APP model have resulted displaying at product families levels, the demand estimate, optimal production, inventoryn and backorder levels together with man hour for both regular and overtime used. The modeling option Sub-contracting had been chosen to be excluded by the user, in this example. Thus, the sub-contracting has been left out from the APP and not displayed in the results table. The first table Demand Estimates in Fig. 4 lists the demand estimates for every product family for the whole planning horizon.

The user can choose to quit or re-generate the APP is the results are unsatisfactory or if the user wants to manipulate the modeling options to analyse the results. Upon the final generation of APP, the user can move on to create the MPS. Clicking on the Disaggregate! button, opens up the disaggregate window/module.

Disaggregate module: Once the APP is confirmed, the weekly end item production quantities are disaggregated into MPS. The information is displayed in the table of the disaggregate module is for each assembly line, each product family and each product item, information displayed include demand estimate, production, inventory, backorders and subcontracting levels. Figure 5 shows the disaggregate module of the user-interface system. Depending on the modeling options chosen by the user in the aggregate module, the weights boxes will be allowed to retrieve values of weights from the user. The assignment of weights to the decision variables follows the following priority structure: Overproduction followed by overachievement of inventory level, followed by positive deviation of backorders levels, followed by positive deviation of sub-contracting levels and positive deviation of overtime.

The assignment values allowed ranges from 1-10000. The highest value represents the highest priority when calculating the MPS. The user can choose to quit or re-generate the MPS if the results are unsatisfactory or if the user wants to manipulate the goal priority weights to analyze the results. An email notification will be sent to the management of F2, alerting that there was a change/re-generation of the production plans, upon any generation of the plans.

The web-based application (WEB): The objective of the WEB is to share the production plans generated at F1 with the management of F2. The Web application has been developed using the ASP technology. The client-side scripting used is Java Script, while the server-side was designed using VBScript. The server hosts the web pages by publishing it to the Internet. The client in this context refers to the management of F1 while the server is determined to be at F2. A client is defined as a requester of services and a server is defined as the provider of services.

Upon successful login, the user can choose to view the APP or the MPS. Results are shown for every assembly line, product family and product item for each week. The following activity diagram in Fig. 6 shows the user activities around the WEB and Fig. 7 and 8 show the APP and MPS WEB pages that has been developed.

TESTING AND VALIDATION

The MUSICOS is put to the test to validate its reliability and robustness in providing users with the decision-aid to generate feasible and optimal production plans and to share the information between the facilities. Tests were performed onto the architecture of the whole system and also a model validation to ensure

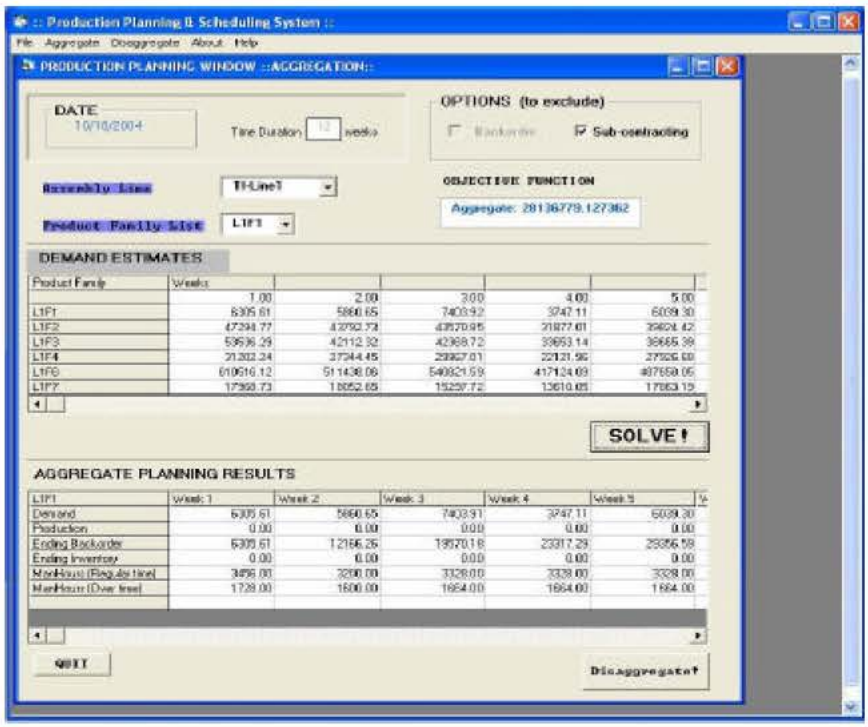

Fig. 4: The APP module

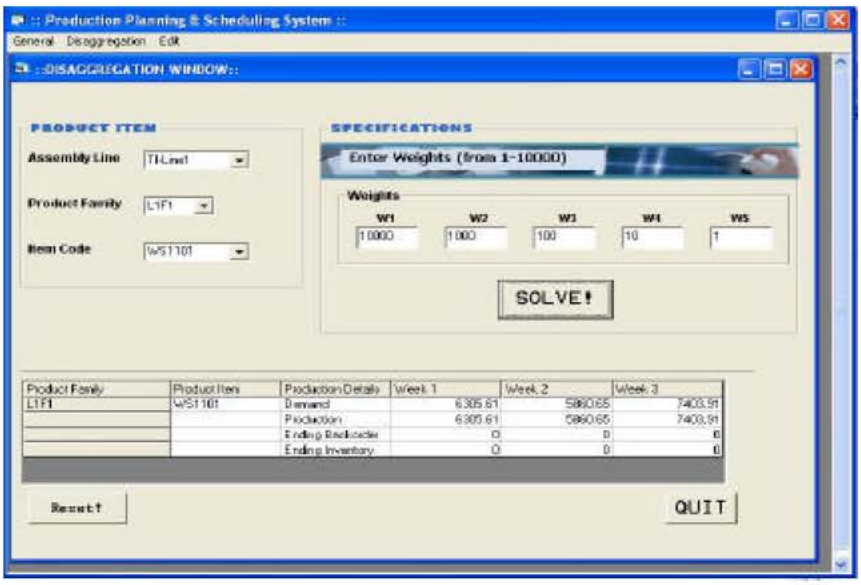

Fig. 5: The MPS module

that the models provide the most optimal results. There are two tests that we carried out to validate the input data. The input data is obtained from a real manufacturing facility. The main purpose of these tests is to test the efficiency and reliability of the modules in providing feasible optimal solutions, given several scenarios. The tests are divided into two sections as the following:

- Generate the random demand using two parameters in the demand distribution. The scenarios generated will be used as input for the APP and MPS models.
- The MPS model is executed using different priority goals structure in order to examine the impact of different priority structures and goals weight on MPS result generation.

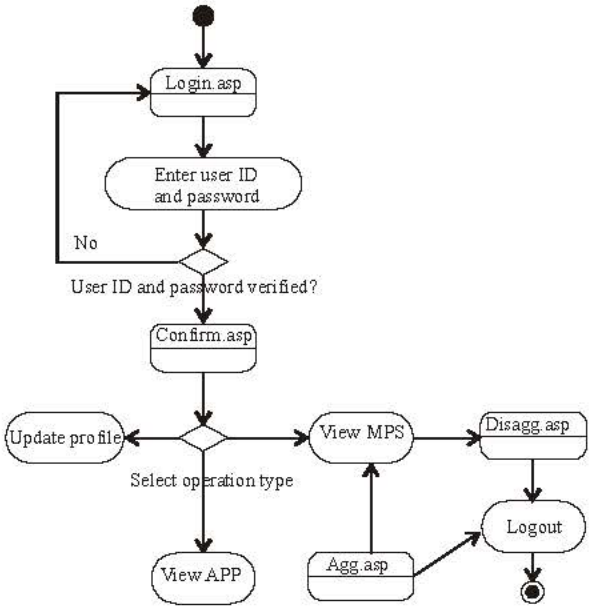

Fig. 6: User activities with WEB

The above two sections are elaborated to include procedures as following:

Impact of demand variation and product-mix variation: In this section, the random demand is generated using two parameters in the demand distribution as proposed by Xie *et al.*[13]: Demand Variation (DV) which represents the variability of the total demand and product-mix variation (MV) which represents the variability in the proportion of the demand for each of the 36 product items in the total demand for two assembly lines. The overall market demand and the detailed product-mix are two crucial concerns of demand management, Vollmann *et al.*[14]. Three levels of DV factor are used in this study. DV is set at 10 and 20 and 40% of the average total demand for two levels, respectively, representing the low, medium and high levels of variations in the normal random noise component of the total demand for 36 products. The magnitudes of the noise component for MV are also varied at three levels. MV is set at 10, 20 and 40% of the average proportion of individual item demand for the three

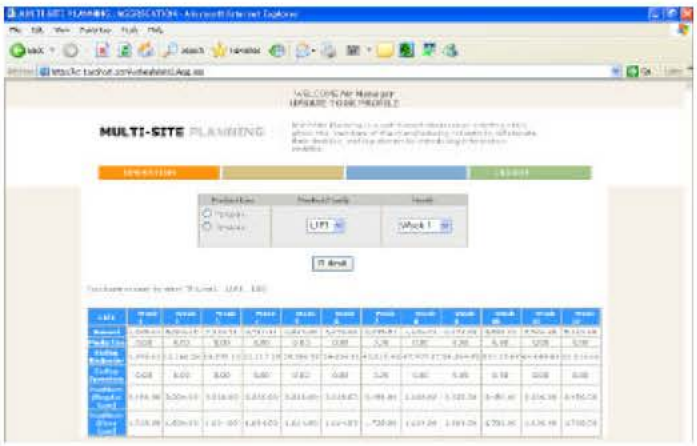

Fig. 7: The APP display page

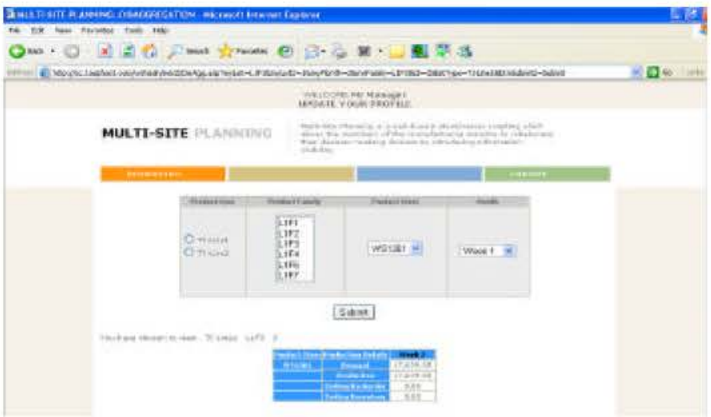

Fig. 8: The MPS display page

levels, respectively, representing the low, medium and high levels of variations in the normal random noise component of the MV proportion for the 36 products. There are a total of 90 different demand patterns (scenarios) representing different combinations of total DV and MV, 45 for each assembly line.

Priority structures and goal weights on MPS achievement: After the APP has been generated, the facility management of F1 has further decided to address the following decision entities at the MPS level of planning. Excess of production level in each planning period, Excess of ending inventory in each planning period, Excess of backorder level in each planning period, Excess of sub-contracting in each planning period, Excess of manpower hours (overtime) in each planning period.

At an earlier stage of development, the user needs to assign weights to the goals in Microsoft Excel. The assignment of goals is designed to be interactive. Thus, the user can easily change the priority structure by entering the different weights to his/her preference to examine different scenarios, through the interface (instead of Excel). Different weights are selected to represent the goal priorities and assigned to the variables. For this research, two different priority structures representing different combinations of the five goals were created. Table 1 displays the chosen priority structures to be tested.

Table 1: Different priority structure

First Priority	Second Priority	Third Priority	Fourth Priority	Fifth Priority	Priority goals structure
Minimize over Production	Minimize over Backorder	Minimize over Inventory	Minimize Subcontr-acting	Minimize Over time	PBISW
Minimize Subcontr-acting	Minimize over Backorder	Minimize over Inventory	Minimize over Production	Minimize Over time	SBIPW

Table 2: TI-Line1 with Goal Priority PBISW

			Goals achievements (4 weeks)			
DV	MV	Goals	1	2	3	4
0.1	0.1	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
	0.2	Minimize over production	Yes	No	Yes	No
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
	0.4	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
0.2	0.1	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
	0.2	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
	0.4	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
0.4	0.1	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
	0.2	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes
	0.4	Minimize over production	Yes	Yes	Yes	Yes
		Minimize over backorder	Yes	Yes	Yes	Yes
		Minimize over inventory	Yes	Yes	Yes	Yes
		Minimize over Subcontracting	No	No	No	No
		Minimize over time	Yes	Yes	Yes	Yes

RESULTS AND DISCUSSION

The model validation results are not investigated in such details as to discover why the impact of DV and MV and priority goals differs for both the assembly lines in this study. It is also not the intention of this study to discover or analyse the best ways or algorithms to generate APP solution with the most minimum cost. Table 2 shows the analysis from the results obtained from the demand variation and product-mix variation random generated demand data for TI-Line 1 with goal structure PBISW. All scenarios for both assembly lines, TI-Line1 and TI-Line2, are able to generate feasible solutions. The first priority goal is to minimize the deviations for over production. From the results of Table 2, this goal is achieved for every set of scenario (DV/MV) except when DV=0.1; MV=0.2, for weeks 2 and 4. Positive deviations of backorder and inventory are also minimised. In order to satisfy the first goal, all demands are met from the sub-contracting or inventory. Therefore, the fourth goal to minimise sub-contracting is not achieved for all scenarios since it is assigned the second lowest important in the priority structure.

In the priority structure of SBIPW, the first goal to minimise the sub-contracting is achieved. Goals to minimise backorder and inventory is achieved as well, for all scenarios when, DV = 0.1 and 0.2. When, DV = 0.4; MV = 0.1 and 0.2, the positive deviations from backorder

is not minimised for week 1 and 2. In the last scenario, when DV=0.4; MV=0.4, it is noticed that minimising backorder is not achieved for week 4. All over productions are not minimised when DV=0.4. This is because the demands are too high to be satisfied in the productions or since minimising backorder is placed as the fourth importance. Therefore the remaining unsatisfied demands are met through backorder. As a conclusion, it is to say that the assignment of priority goal weights affects the outcome of the MPS results. Besides analysing the goal priority structures, combinations of DV and MV are also valuable for the manager to find out the combination which contributes to the lowest total costs. Simply, a calculation to add up the total costs for 12 weeks is performed. Then, compare that against the actual generated total cost (this is the objective function of the OPL aggregation model which it tries to minimize).

CONCLUSIONS

This study presents the software architecture developed to address the collaboration of multi-site production planning problem. The architecture has many practical features including the introduction of real-time information updates for the access of user via the Internet and thus, can overcome some of the basic deficiencies of existing production planning software packages. Mathematical models for generating production plans were developed and its model data were validated. Decisions made are enhanced as the user is given the option to include or exclude constraints into the mathematical models. The architecture framework has been tested using data of a real company and has generated workable and robust solution. It has also resulted in many useful insights and practical implications for management. The availability of updated information on the changes of APP/MPS in real-time enables the management of the testing-distribution facility to know the current details of the production plans. Since the customers' orders are subjected to variations (cancellations/additions), the need to collaborate decision-making is ever important. With the proposed web application, information is updated and accessible in real-time, thus increasing the value of information significantly.

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