A Comparative Analysis of Disaggregation Types in Hierarchical Production Planning

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Abstract: - Supply chain management has become an important component of global economy through competitive environment among businesses. Production planning is a significant major element of value chains, and considered in two different models namely monolithic and hierarchical. Hierarchical approach divides the problems into several stages according to product type and product family, and provides problem solving much more easily. This study introduces a comparative analysis for disaggregation types of two research papers which utilize hierarchical production planning models in supply chain processes.

Key-Words: - Hierarchical production planning, comparative analysis, disaggregation types, supply chain

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1 Introduction

Nowadays, supply chain management becomes more and more important day by day as a result of rapid competition and there is a need for cost reduction in supply chain operations that include logistics activities. Supply chain departments of firms have become major elements instead of support elements in the global economy. Supply chain management has become a significant element in the global economy as a result of competition among the businesses. Supply chain is seen as the area to minimize the cost [1]. In the global economy, the supply chain operations become major elements in the firms instead of support elements. With the increased competition, it can be said that firms want to establish more sustainable and successful relationships wih their suppliers. However, supply chain operations have exposed to different kinds of risks in nowadays as a result of globalization [2].

Production planning problems are generally constructed in two different ways namely monolithic and hierarchical. The monolithic approach solved a mixed integer linear programming model for all the items, while the hierarchical approach, illustrated in Figure 1, divides the problem into several stages corresponding to product type and product family. Since the detailed problems can be solved much more easily, the hierarchical models may satisfy managers' requirements for a quick solution than a monolithic approach [3].

The aim of this study is to provide a comparative analysis for disaggregation types of two research papers which use hierarchical production planning models in supply chain processes.

The rest of the paper is organized as follows. Section 2 reviews the literature on hierarchical production planning applications in supply chain. Section 3 provides the notes on Xue et al. [3] and Gansterer [4], respectively. Concluding remarks and future research directions are delineated in Section 4.

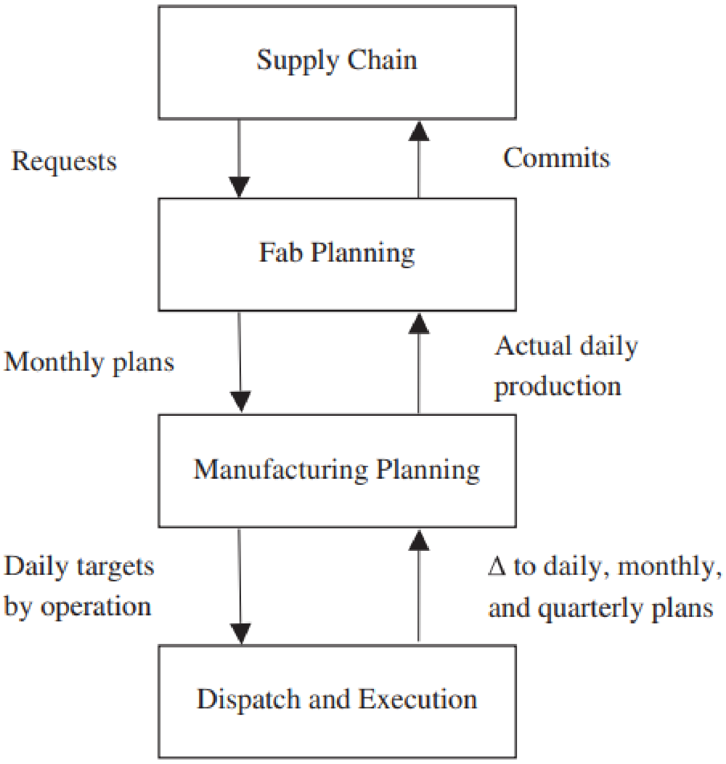

Figure 1. Hierarchical production planning structure [5]

2 Literature Review on Hierarchical Production Planning Applications in Supply Chain

Over the last decade, scholars contributed to the hierarchical production planning applications on supply chain. Selot et al. [6] developed a hierarchical multiobjective programming model for a supply chain of a gas production system in Malaysia. You and Grossmann [7] developed a hierarchical production plan for different decision making stages namely strategic and operational, and illustrated the application with two numerical examples of polystyrene supply chains. Caramanis et al. [8] developed a hierarchical production planning model by disaggregating the time as weekly and hourly, and applied it for a supply chain performance. Gharbi et al. [9] proposed a methodology which enables obtaining an optimal and reactive tactical plan of supply chain in uncertain environment. The method was centered upon two stage decisional framework. The first stage carries out an aggregate planning by minimizing the production costs while the second stage makes the planning of the aggregate level and takes into consideration the constraints ignored at the aggregate level.

Sawik [10] suggested a monolithic and a hierarchical approach for scheduling material manufacturing, material supply and product assembly in a customer driven supply chain, and provided a comparative analysis between these two models. Boulaksil et al. [11] proposed an iterative two-stage hierarchical production planning model for capacity planning of an outsourced supply chain. First, they solved the aggregate problem that is integer programming model. Second, they conducted a simulation study in which a mathematical programming was solved in order to evaluate system performance. Xue et al. [3] introduced an aggregate production planning model, and family disaggregation and scheduling models in hierarchical production planning by taking into account setup times. Optimal production plan for each product type and product family in each period is obtained by proposed approach. The model was applied to a mold manufacturing factory.

Li et al. [12] proposed a novel hierarchical belief-rule-based inference methodology for an aggregate production planning under uncertain environment of demand. They carried out a case study in a paint factory. Wang and Huang [13] introduced a two-level programming model for indicating an accurate decision for recycle volume, time of the end-of-life product and recovery procedures. Fahimnia et al. [14] compared the results of a mixed-integer nonlinear production planning model and a hierarchical production model in order to investigate the benefits of cost reduction obtained from a supply chain via global integration of production and distribution decisions. Case study was conducted in an automotive company.

Manzini et al. [15] proposed a top-down approach that combines the strategic planning, the tactical planning, and the operational planning of distribution networks. The influence of the strategic and tactical decisions on the performance of the operational planning was assessed by employing a hierarchical planning approach in logistics sector. Jin et al. [16] investigated if the different patterns of data aggregation affect the measures of the supply chain, and made the use of hierarchical linear programming model for testing the influences of the data aggregation on various measures. The model was applied in a company performing in the retail sector. O'Reilly et al. [17] discussed the role of hierarchical production planning, and aimed at implement hierarchical production strategies to the food manufacturer companies.

Vargas et al. [18] introduced a business-to-business model which addresses the issue of dealing with unexpected events in hierarchical production planning, and how the B2B framework is incorporated into programming model. The case study was conducted in a Spanish ceramic tile factory. Acar and Atadeniz [19] evaluated the effect of integrated production planning for the value chain of a global lubricant manufacturer company. They considered cost and performance indicators in an uncertain environment of demand, and proposed a mixed integer programming model for the hierarchical framework of the problem. Finally, they utilized ANOVA in order to identify the relationships among experimental factors.

Gansterer [4] introduced a hierarchical production planning framework by solving a linear programming model which identifies the influence of aggregate planning in make-to-order environment. Case study was conducted by obtaining real data from a supplier firm performed in automotive industry. Bakhshizadeh et al. [20] proposed a hierarchical programming model that is more efficient for value chains in which some elements are more effective and powerful than the others. Moreover, decision makers in the aggregate level indicated their objectives and decisions, and asked the detailed level of the organization to optimize the objectives separately. The application was employed in a car company in order to test the robustness of the proposed approach. Paiva et al. [21] developed a hierarchical optimization model for the sugar-alcohol energy sector with robust optimization analysis to provide managerial insights. Munduteguy [22] explored how a foreman deals with work flexibility by constructing a hierarchical production planning framework. Albornoz et al. [23] used hierarchical production planning for zone delineation and crop planning under uncertainty. Xue and Offodile [24] integrated a non-linear mixed integer programming model and hierarchical production planning approach for optimizing dynamic manufacturing systems in a metal mold manufacturing plant. Gahm et al. [25] applied a machine learning method for the anticipation of complex nesting solutions in hierarchical production planning in metal processing sector.

The table format of the literature survey with regard to the research area of the reviewed papers is provided in Table 1.

Table 1. Literature survey with regard to the research area

Author(s)	**Year**	**Research Area**
Selot et al.	2008	Gas production
You and Grossmann	2008	Polystyrene supply chain
Caramanis et al.	2009	Supply chain performance
Gharbi et al.	2009	Raw material supply
Sawik	2009	Material supply
Boulaksil et al.	2009	Outsourced supply chain
Xue et al.	2011	Mold manufacturing
Steinruecke and Jahr	2012	Logistics sector
Li et al.	2013	Paint industry
Wang and Huang	2013	Recycling
Fahimnia et al.	2013	Automotive sector
Manzini et al.	2014	Logistics industry
Jin et al.	2015	Retail sector
O'Reilly et al.	2015	Food manufacturing
Vargas et al.	2015	Ceramic tile industry
Acar and Atadeniz	2015	Lubricant manufacturing
Gansterer	2015	Automotive sector
Bakhshizadeh et al.	2016	Automotive sector
Paiva et al.	2020	Energy sector
Munduteguy	2020	Logistics sector
Albornoz et al.	2020	Agriculture industry
Xue and Offodile	2020	Mold manufacturing
Gahm et al.	2022	Metal processing industry

3 Comparative Analysis Between Two Hierarchical Production Planning Approaches

In this section of the study, a comparative analysis between Xue et al. [4] and Gansterer [5] is provided in order to better understand the difference between aggregate planning models and disaggregation types in hierarchical production planning.

3.1 A Note on Xue, Offodile, Zhou, and Troutt's Hierarchical Production Planning Approach

Xue et al. [3] developed an integrated model for aggregate production planning and family disaggregation planning. The model identifies the optimal production plan for each product type and product family in each period of production, and obtains a big amount of cost savings. The model is applied to a mold manufacturing factory. At the type level, the aggregate production planning model taking into consideration mid-term decisions is formulated as follows:

$$\min \sum_{t=1}^{T}[\mathrm{ch}_t H_t + \mathrm{cf}_t F_t + \sum_{m=1}^{M}(\mathrm{tc}_{\mathrm{mt}} X_{\mathrm{mt}} + h_{\mathrm{mt}} I_{\mathrm{mt}} + \mathrm{cs}_{\mathrm{mt}} S_{\mathrm{mt}} + \mathrm{cb}_{\mathrm{mt}} B_{\mathrm{mt}} + \mathrm{cr}_{\mathrm{mt}} R_{\mathrm{mt}} + \mathrm{co}_{\mathrm{mt}} O_{\mathrm{mt}})] \tag{1}$$

subject to

$$I_{m,t-1} + X_{\mathrm{mt}} + S_{\mathrm{mt}} - I_{\mathrm{mt}} + B_{\mathrm{mt}} - B_{m,t-1} = d_{\mathrm{mt}} \qquad \forall m,t \tag{2}$$

$$\sum_{m=1}^{M} \mathrm{ut}_{\mathrm{mt}} X_{\mathrm{mt}} \le (\mathrm{AR}_t + \mathrm{AO}_t)A \qquad \forall t \tag{3}$$

$$\mathrm{ut}_{\mathrm{mt}} X_{\mathrm{mt}} = R_{\mathrm{mt}} + O_{\mathrm{mt}} \qquad \forall m,t \tag{4}$$

$$\sum_{m=1}^{M} O_{\mathrm{mt}} \le \mathrm{AO}_t = \mathrm{poAR}_t \qquad \forall t \tag{5}$$

$$S_{\mathrm{mt}} \le \mathrm{CAS}_{\mathrm{mt}} \qquad \forall m,t \tag{6}$$

$$B_{\mathrm{mt}} \le \mathrm{CAB}_{\mathrm{mt}} \qquad \forall m,t \tag{7}$$

$$\mathrm{AR}_t - \mathrm{AR}_{t-1} = H_t - F_t \qquad \forall t \tag{8}$$

$$\sum_{m=1}^{M} \mathrm{ua}_m I_{\mathrm{mt}} \le \mathrm{OS} \qquad \forall t \tag{9}$$

$$X_{\mathrm{mt}}, I_{\mathrm{mt}}, B_{\mathrm{mt}}, S_{\mathrm{mt}}, R_{\mathrm{mt}}, O_{\mathrm{mt}}, H_t, F_t \ge 0 \qquad \forall m,t \tag{10}$$

where M and T represent the index of type and index of period, respectively. $\mathrm{tc}_{\mathrm{mt}}$ refers to the unit production cost (materials + overhead), $\mathrm{ut}_{\mathrm{mt}}$ refers to the processing time for type *m* in period *t*. h_{mt} , $\mathrm{cs}_{\mathrm{mt}}$, $\mathrm{cb}_{\mathrm{mt}}$ signify unit inventory carrying, subcontracting and backordering costs for type *m* in period *t*. $\mathrm{cr}_{\mathrm{mt}}$ and $\mathrm{co}_{\mathrm{mt}}$ represent regular time and overtime costs per man-hour for for type *m* in period *t*. ch_t and cf_t refer to the cost of hiring one man-hour and laying off one man-hour in period *t*. d_{mt} refers to the net demand for type *m* in period *t*. *A* signifies the capacity allowance percentage (used for allowing machine breakdowns, earlier due dates, etc.). po represents permitted percentage of overtime to available regular time. $\mathrm{CAS}_{\mathrm{mt}}$ refers to maximum subcontracting capacity costs for type *m* in period *t*. $\mathrm{CAB}_{\mathrm{mt}}$ signifies maximum backordering quantity permitted for type *m* in period *t*. ua_m represents the space occupied by each unit inventory of type *m*. OS refers to the total available space for inventory storage. X_{mt} and I_{mt}signify production and inventory level of for type *m* in period *t*. S_{mt} and B_{mt} represent subcontracting and backordering quantity of type *m* in period *t*. $H_t$and $F_t$refer to man-hours of regular time hired and laid off in period *t*. R_{mt} and O_{mt} signify regular time and overtime hours consumed by type type *m* in period *t*. AR_t and AO_t represent available regular time and overtime hours in period *t*.

In the model formulated above, the objective function aims to minimize the total costs in the planning horizon. Production balance equations are given in Constraints (2). Capacity bounds are provided by Constraints (3). Constraints (4) are total capacity consumed by each type of period. Constraints (5) guarantee that the total overtime in one period will not exceed available overtime. Subcontracting capacity limits are given in Constraints (6) and backordering limits are provided in Constraints (7). Labor force balance equations and inventory storage space bounds are given in Constraints (9).

Second, the authors develop a family disaggregation model which aims to minimize setup costs via objective function, and the constraints ensure that the total quantity assigned to all families are equal to the type quantity determined by aggregate plan in the current period. The disaggregation model is provided below:

$$\min \sum_{i=1}^{I} \partial_i \, \mathrm{ub}_{\mathrm{it}} / l_{\mathrm{it}} \tag{11}$$

subject to

$$\sum_{i \in j(m)} l_{\mathrm{it}} = X_{\mathrm{mt}} \qquad \forall m,t \tag{12}$$

$$\mathrm{lb}_{\mathrm{it}} \le l_{\mathrm{it}} \le \mathrm{ub}_{\mathrm{it}} \qquad \forall i,t \tag{13}$$

where Irepresents the index of the family, *j*(*m*) refers to the set of families pertaining to type *m*, ∂_i signifies setup cost of family *i*, $\mathrm{lb}_{\mathrm{it}}$and $\mathrm{ub}_{\mathrm{it}}$represents lower bound and upper bound of the lot size of family *i* in period *t*, and l_{it}represents the lot size of family *i* in period *t*.

3.1 A Note on Gansterer's Aggregate Planning Approach

Gansterer [4] provided a hierarchical production planning framework in which aggregate production plan is developed as a linear programming model and solved to obtain the optimal solution. The mathematical programming model is as

$$\min \sum_{p\in P}\sum_{t\in T} h_p\, l_{\mathrm{pt}} + \sum_{p\in P}\sum_{t\in T} m_p n_{\mathrm{pt}} \tag{14}$$

subject to

$$\sum_{p\in P} a_{\mathrm{pj}}\, x_{\mathrm{pt}} \le K_{\mathrm{jt}} \quad \forall j \in J, \qquad t \in T \tag{15}$$

$$l_{\mathrm{pt}} - n_{\mathrm{pt}} = l_{p,t-1} - n_{p,t-1} + x_{\mathrm{pt}} - d_{\mathrm{pt}} \qquad \forall p \in P, \qquad t \in T/\{1\} \tag{16}$$

$$x_{\mathrm{pt}}, l_{\mathrm{pt}}, n_{\mathrm{pt}} \ge 0 \qquad \forall p \in P, \qquad t \in T \tag{17}$$

where *P*, *T* and *J* represent the set of product families, the set of time periods and the set of machine groups, respectively. x_{pt}refers to production amount of product family *p* in period *t*. l_{pt} signifies inventory level of product family *p* in period *t*. n_{pt} represents backorders for product family *p* in period *t*. a_{pj} refers to the capacity consumption factor, $h_p$signifies inventory cost factor, m_p represents cost factor for backorders. d_{pt} and K_{jt}refer to forecasted demand and available capacity.

The objective function is to minimize inventory and backordering costs. Constraints (15) guarantee that capacities are not exceeded. Production balance equations are given in Constraints (16). Constraints (17) provide non-negativity of decision variables.

The model is constructed by using aggregate data with regard to time periods, capacities and product groups. Production amounts are computed for product families instead of products. The aggregate production plan is utilized for balancing production quantities of product families on a monthly basis. Subsequently, the aggregate plan is converted to MPS and then MRP where it is disaggregated in order to obtain production quantities for end products rather than product families.

4 Concluding Remarks

This work presents a comparative analysis for disaggregation types of two research papers which utilize hierarchical production planning models in supply chain processes. For that reason, a literature review on hierarchical production planning application in supply chain is provided. Subsequently, some interpretations for Xue et al. [3] and Gansterer [4] are given and the differences in terms of disaggregation types of these two approaches are observed. Future research will focus on real case applications by solving these models to optimality utilizing real data.

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