Plant capacity assessment through a simulation approach

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Abstract: - World-wide competition and a more and more pressing market demand for a reduction in the time-to-market induce to move the productivity’s levels analysis between supply chain’s several levels to allow a better planning of the entire production and assembling cycle in the aim of reducing the time of total completion up to the time of delivery of the complete product. Therefore the coordination and planning of the various rings of the chain and the estimate of the productive capability of the various production units become fundamental for a coherent evaluation of promised delivery times. More and more frequently and in greater detail the companies at the “end of the network” require, through capacity assessment a verification of the available productive capacity of the manufacturing units, both from a quality and quantity point of view, that the each single firm can dedicate to a certain type of production. In line with the theories of advanced planning and scheduling, a simulation model is presented that allows the elaboration of a realistic operative plan of production through the verification of finite capacity scheduling of the loading of resources. This is a draft of a model of discreet events, that allows knowledge of the state system at any moment allowing ample flexibility, as regards attributions, variable and logistic flows. The model tends to minimize costs of stocking and of set-up, considering other production costs as constant.

Key-Words: - Supply chain management, advanced planning and scheduling, finite capacity scheduling, capacity management, simulation.

1 Introduction

Often the connection between the concepts of supply chain management, advanced planning and scheduling and capacity management (all terms that are diffuse with the recent literature) is not clear, so first of all let us try to clarify the meaning and the connection, that are being investigated in this article. Supply chain management is today the most complete term to indicate the optimized flow of materials during the whole process of transformation. Advanced planning and Scheduling are instrument that are able to take into account the contingencies that deviate the rhythm of production by the production plan. This analysis of detail is focused in our case in the study of the best use of the productive capacity of a manufacturing plant. So that the best short term plan can be determined that minimizes production costs and ensures that delivery dates are respected. The most adapt level of present productive capacity is thus determined through the simulative instrument, which takes into account disturber elements in the medium term.

2 State of art

In the last twenty years it has been developed and diffused the concept of supply chain management. The field of interest of such approach is very wide, born like fusion of multiple specific aspects. It consists, as Christopher said, in “a network of organizations that are involved, through upstream and downstream linkages in the different processes and activities that produce value in the form of products and services in the hand of the ultimate consumer”[18].
The integrated SC or supply network, goes beyond the traditional concept of logistics and flow of materials, and emphasizes the necessity of the interaction between the several actors of the chain during the creation of customer service. The level of service, in fact, as a diffused literature testifies, is now the focal point in a process of selection and increase; so for developing better performances and for creating value, companies must interact each other creating organized rows and with an aware common vision, because in the global-competition the inside competences become insufficient. Accord to Stadtler [1] in fact, “in case the organizational units belong to one single enterprise an intra-organizational SC is given. Here, hierarchical coordination is possible and prevailing. While hierarchical coordination in globally operating enterprises is already a demanding task, the real challenge arises in an inter-organizational SC where hierarchical coordination is no longer possible”.

In summary supply chain management is not a novel management paradigm as such. Instead it is a new point of view for understanding the processes and their problems, useful for improve them and make more quick the flow through chain’s levels, [1], [5], [6]. In this endeavour supply chain management is a large container in which are present,
inventory & purchases management, capacity management, production planning and scheduling, suppliers monitoring and management, distribution management.

Now we assume the point of view of a company in central position inside the network; neither in the start, the supplier network that procures the materials and partly finished, neither at the end, the typical final customer’s location. The “company in the middle” has surely necessity to relate itself with others elements of the chain and to coordinate the customer’s requirements to the supplier deliveries and to the logistic flow’s organization; it’s necessary to realize the customers, suppliers and flow integration. The “company in the middle” can’t manage all these things if it doesn’t realize the internal integration and organization. It passes through these strategic levers: to evaluate a coherent production levels of current capacity, to define the business rules, the internal functions and procedures, to make a good resources’ scheduling considering the variations of the constraints and the changes of customer requirements and the waiting time in queue for WIP first to arrive at the work-station.

The MRP’s elaboration may be unfeasible. On the shop floor can arise many problems such as increasing of workload or the bottleneck shifting and so on, that lengthen the real production lead-time. Therefore usually the planners tend to rise the lead-times in order to get better performance. However this behaviour causes higher forecast errors, longer queues, more work in process (WIP), lower machine utilization, less throughput, higher production costs and ever more unreliable planned lead times. [3]

Now is widely recognized that the process batching involves a convex relationship of lead time as a function of processing batch. So exists an optimal solution to minimize lead time, and deviating from which, there are substantial problems in the case of high utilization and uncertainty. Moreover, this convex relationship is not symmetrical, meaning that a deviation above and below the optimal size does not have the same impact on the lead time [4]. The Advanced Planning and Scheduling’s aim is the integration between MRP and production scheduling to obtain a realistic production schedule for the shop floor. The APS describes any computer program that use advanced mathematical algorithms or logic to perform optimization or simulation on finite capacity scheduling, sourcing, resource planning, forecasting, demand management and others [7]. These techniques evaluate more constraints and business rules to be decision support and to make a good forecast of availability-to-promise and capability-to-promise, through the choice among different views. Although developed independently by different software vendors, APS exhibits a common architecture based on the principles of hierarchical planning. It’s necessary a coordination to support the material flow across a supply chain and related business functions: procurement, production, transport and distribution [1]. As we have above seen, the planning tasks can be considered at different levels of aggregation from long term to detailed short term and are associated to software APS modules. The SCM is driven by demand, so
the starting point of planning is the forecasted demand in the longer planning horizon, then in the mid-term is elaborated the master planning and in the short term it needs to make Purchasing & Material Requirement Planning, Production Planning and scheduling and Distribution & Transport Planning.

Recently with the SCM diffusion concept, the research is focused on to respect job expected due-date with outsourcing and scheduling problem. Chung et al. (2000) started with the concept that the adjustment of machine capacity is possible through outsourcing. He divided the job-shop problem in smaller subproblems by a heuristic solution procedure towards optimality. Hae Lee et al. (2002) [2] created an integrated model using alternative machines with outsourcing. If any job can be scheduled on more than one machine and may have flexible operation sequences it is possible to obtain a better use of resource considering all the different combinations to make an operative plan. Traditionally, in the beginning, the process planning is defined, then actual planning is determined; in this case we ignore the relationship between scheduling and process planning. Therefore they proposed a new integrated process planning and scheduling and outsourcing that minimized the makespan, considering alternative machines or alternative sequences of operation with precedence constraints and outsourcing. In fact, although outsourcing was considered given due date constraints, the reality reveals that outsourcing is not efficiently integrated with process planning and scheduling, because they used a fixed machine for an operation or a fixed operation sequence. To solve the model a GA-based approach was developed.

Chen et a. [3] presented a MIP (mixed integer programming) model for APS, which succeeded in a system integration of the production planning and shop floor scheduling problems considering capacity constraints, operation sequences, lead times and due dates in a multi-order environment. The aim of the model was to seek the minimum cost of both production idle time and tardiness or earliness penalty of an order; the result was production schedules with starting time and finish time for each item of an order.

Planning techniques through ERP systems have the aim of finding a feasible solution that respects the ties and needs of the system; but feasible is very different from optimum. In the continuous improvement optical and date the crescent competitiveness, an instrument has looked for and found for the capacity assessment of the manufacturing plant, object of study.

In the first issue we used a integer linear programming model, Capacitated Lot-Sizing Problem with linked Lot-size [8], an algorithm which optimizes operative production planning. Receiving in input the master production schedule (MPS) and considering processing time of each phase, for each product and for all days, the aim of the selected model is to give back the economic optimal batch to minimize production costs (stocking costs, set-up costs and overtime costs). During model implementation, a “structural” problem came up, showing the model inadequacy to represent specific industrial reality dynamics. In fact, in accordance with relationships, the model does not take into account precedence constraints among phases, but tending to saturate the resource’s capability, makes the various phases begin at the same time, which in reality is impossible. C.L.S.P.L is unsuitable for reflecting and solving planning problems of this industrial reality for two fundamental reasons: it do not give the solution to dynamic problems scheduling and we do not get necessary computing power (NP-hard problem).

3 The simulation, a capacity assessment tool

Simulation is a technique that we use in order to formulate and solve many problems. We can also consider as simulation problems support software for production management, but these are static simulators, that only consider discreet parameters and don’t take into account the real staff availability (due to holidays or leaves), of the movements of partly finished inside the plant, of the stochastic nature of many variable that are present in a company system. Time of arrival of the jobs, buying and delivery of materials and procurement in general, the duration itself of the operations and the time which the movement actually takes, are all casual variable [4], [9]. Simulation allows the study of dynamic problems across successive periods of time, during which, the dynamic models are able to ascertain how the situation evolves in time and to understand the successive effect of decisions made. Simulation therefore is a strategic means of foreseeing those situations that would be difficult and costly to examine for real, so that consciously examined decisions can be made. In practice, various kind of problem are simulated more and more often, from the distribution of goods, to production in progress, to the management of arrivals and departures of every means of transport. In the stochastic models we can also have as variables in entry functions of probability density and known probabilistic distributions, this means that with the same combination of situations infinite possible histories can be generated. So a real sampling of possible histories can be obtained and with these the main characteristics of system functioning can be evaluated [9].

Accord to Musselman et al.(2002) “Modern Enterprise Resource Planning (ERP) systems contain all the data necessary for detailed production planning”[10]. It contains product information, such as bill of material and routing of parts, system information such as equipment, manpower, and shift schedules; it also holds status information such as the current order book, work in process, inventory level, and released purchase orders. “This is what is needed for an Advanced Planning and Scheduling function to determine how to efficiently plan a plant’s operations and to replan
quickly and accurately based on changing requirements” [10]. The worse defect of ERP system is that limits on manufacturing capacity are not considered and the lead times are calculated as fixed quantity. The simulation can be used to test the result of the MRP plan, putting the job start time in a virtual factory that simulates the manufacturing of single parts considering expected delivery time and the consequent queues. The APS integrates the approaches of planning and scheduling, in fact, in the middle term, the planner module produces a plan that respects the capacity limits of system, then feeds a scheduler module that produces detailed lists of operations on work-centers. Then it returns these information to the planner module to use them in the next period to provide realistic estimates of availability to promise. In the scheduling phase, the APS uses the same information provided to the planning phase but uses a more detailed representation of the data. The information not used by planner module are:

- run times and setup times which vary according to the machine and operators actually assigned;
- quality requirements;
- characteristics of the part;
- work parameters;
- rules for selecting the jobs;
- allowable shift overruns.

The scheduler module works in the short time because the utility of a schedule degenerates quickly as time passes and the simulation used for generating a schedule is usually deterministic because the causes of changes on shop floor for urgent order, machine-stop and late delivery order and the real possibilities to work (about tools, materials, shifts, operator’s ability...) must be quickly settled and estimated. The figure 3 shows the input and output flows between the ERP function and scheduling function. The scheduled jobs by scheduler module and purchase orders by ERP are returned to the planner module for the next planning run. This feedback will allow to have good plans[10].

With simulation we can estimate variations of a system; the APS has the capability to copy ERP data and experiment the effects of the changes. “Through computer simulation it is possible to select those operational decisions that maximize an objective function or a system performance parameter, and to evaluate the effects of these decisions with the not controllable factors variability”. Recently is diffusing the use of simulation as support to planning and control activities; this is possible through simulation models much more detailed and updatable, in a very little expensive and fast way, according to the real system evolution [14].

N.Ueno et al. (1991) used a model simulation to evaluate the productive capacity and to identify the process bottleneck of a production line. The aim was to determine how best to alleviate the bottlenecks designing new machine specifications and a new process with a minimum cost. In order to find quickly the bottlenecks he individuated a performance measure to know the actual production rate. The simulation result shows that it is possible to achieve the required and to increase of productivity by reduction in performance measure to know the actual production rate. The simulation result shows that it is possible to achieve the required and to increase of productivity by reduction in processing time and setup time [11]. Among the first attempts to integrate simulation with manufacturing planning system there was the scheduler FACTOR, with specific data transfer functions to support integration with any production data system (McFarland 1987). The Musselman approach, as we have seen, of a simulation-based function integrated within ERP, was took again by Mazziotto and Horne (1997) [15] allowing to make “wha-t-if” analyses as well as daily scheduling, that was easily ran and reran on a PC. Simulation has been applied to a variety of scheduling situations in different continuous process Vaidyanathan et al. (1998), Chen et Harlock (1999), Ruiz-Torres and Nakati (1998). Then Marvel et al. (2005) [16]used simulation to validate the capacity planning process as well as generate a feasible schedule for a tier two automobile supplier. The simulation model was able to evaluate the problems connected with the backorders costs and the inventory policies comparing several system configurations in a continuous improvement perspective.

Different approaches are present in literature on the use of simulation models as a tool to improve the performance of a system. Alan et al. [12]. proposed a simulation model to reveal the critical elements of the system and relationship with system to improve the process performance. This is a case in which simulation is a tool to redesign the production process.

More complete system was proposed by Kuhen et al. (2004) for job-shop processes [13]. The authors developed an integrate system to support production planning and control by the employment of Java and database applications (Simulation Based Job Shop Analyzer). It enables to model and simulate the operations of a whatever job-shop system.
and to give the maximum on flexibility and robustness allowing a fully automated generation of the actual simulation model by use of production data from the database ERP.

4 The simulation model in a job shop firm

Now it is proposed a simulation model for planning production orders.

This model was developed through the software ARENA. It was created for a company that produces power generators.

The model was developed so that it can be easily changed. After choosing the number of stations on the basis of optimizations layout of production, using PROCESS blocks are modelled the necessary processing. The SEIZE/RELEASE blocks allow to seize/release any resources needed to carry out the processing. The STATION block aims to define a station.

Within a station you can make many processing. So within a STATION there will be a set of SEIZE, PROCESS and RELEASE blocks.

Using a database you can define the resources needed for processing, the technological sequence and the processing assigned to a station. This approach allows you to maximize the technological sequences considering the queuing at the machines and the utilization of resources.

Of course, some processes may be more complex to manage because they might involve logistics processes and/or outsourcing.

In this case, often, production lots are larger to reduce logistics unit costs. The modelling of such logic in simulation is possible using BATCH blocks. The minimum production lot is a variable to optimise on the basis of logistical costs, holding costs and service level desired.

The complex processes are also subject to greater uncertainty that can be evaluated more precisely if the logic of the model is described in greater detail.

The processing planned to produce the power generators are as follows:

<table>
<thead>
<tr>
<th>#Processing</th>
<th>20 Assembly Engine/Alternator</th>
<th>30 Base Assembly</th>
<th>50 Assembly Power Generator on the base</th>
<th>60 Diesel Plant</th>
<th>70 Electrical System</th>
<th>80 Assembly Silencer</th>
<th>90 Assembly Power Generator container</th>
</tr>
</thead>
</table>

After studying the layout was made the assignment of the processing to the stations as follows. This assignment optimizes also the utilization of resources needed by the various processing.

<table>
<thead>
<tr>
<th>Station</th>
<th>#Processing</th>
<th>Average Processing time (min)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station 1</td>
<td>30</td>
<td>70</td>
<td>4,25</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>52</td>
<td>6,27</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>29</td>
<td>3,01</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>25</td>
<td>1,70</td>
</tr>
<tr>
<td>Station 2</td>
<td>70</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Station 3</td>
<td>90</td>
<td>120</td>
<td>8,57</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>75</td>
<td>2,36</td>
</tr>
</tbody>
</table>

After defining the model of the production process and the processing time you can use the simulation model in two ways:

- forwards
- backwards

In the first way, according to a scheduling provided to the simulator, you can assess how many products available in different periods.

In the second way, through an optimization model is set the quantity to be produced in different periods depending on products demand respecting some constraints. This model interacts with the simulation model to verify that the solution is feasible.

The optimization model uses two matrices:

- P(j,t): shows the amount of product j to be delivered during the period t.
- X(j,t): shows the amount of product j, which is to be launched in production in the period t.

Assuming the same technological cycle for all products j, the only difference is the manufacturing time, considering the developed simulation model (flow shop with two machines in series), we can optimize the matrix X(j, t ), knowing when, how and what we have to produce in the different time buckets.

The optimization can be made on the basis of the following parameters[14]:

\[
\min \sum_{j=1}^{J} \sum_{t=1}^{T} \left[ h_j \cdot I_{jt} \right] + \sum_{j=1}^{J} \sum_{t=1}^{T} \left[ s_{cj} \cdot (Y_{jt}) \right] \\
\text{subject to:} \\
\sum_{j=1}^{J} \sum_{t=1}^{T} R_{jt} = 0 \\
\sum_{j=1}^{J} \sum_{t=1}^{T} X_{jt} \geq 1
\]
\[ \sum_{t=1..T} X_{jt} \geq \sum_{t=1..T} P_{jt} \quad \forall j \in J \quad \forall t \in 1..T-1 \]
\[ \sum_{t=1..T} X_{jt} \leq \sum_{t=1..T} P_{jt} \quad \forall j \in J \]
\[ X_{jt} \in N \]

Where:
- \( h_j \): Holding costs for a unit of item \( j \) in a period; 
- \( s_{cj} \): Setup costs for a lot of item \( j \); 
- \( I_t \): Stocks of item \( j \) at the end of the period \( t \); 
- \( Y_{jt} \): Binary setup variable (1, if there is setup for the item \( j \) in period \( t \), 0 otherwise); 
- \( IR_{jt} \): Number of item \( j \) not delivered at time \( t \); 

This model optimization is generated automatically based on the parameters of the database. The software OptQuest for ARENA perform optimization by the model generated.

References:
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