Optimization of production plan through simulation techniques

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Abstract: - The production costs reduction in a highly competitive environment is a critical success factor. In particular, in fields where outsourcing is used frequently and the impact of the material costs is high, a significant cost reduction can be achieved making more efficient value chain. Moreover, the use of outsourcing is a way to adjust production capacity depending on demand. 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 each single firm can dedicate to a certain type of production. In this paper it is presented a simulation model that allows the elaboration of an operative plan of production through the verification of finite capacity scheduling of resources. The model tends to minimize costs of stocking and set-up, considering other production costs as constant. The simulation is a technique that allows the checking with better precision of the use of the resources with variation of the ties. This approach lead to a high performing instrument in the field of the advanced planning and scheduling through analysis of the various possible views. The auxiliary use of the optimizing tool available in the ARENA software allows an optimal solution, confirming the validity of the study of new applications of the simulative instrument for the verification of productive capacity in the short term.

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 common in 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 instruments able to take into account the contingencies that deviate the rhythm of production from the production plan.

This analysis of details is focused in our case on the study of the best use of a manufacturing plant's productive capacity. 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 the concept of supply chain management has been developed and broadened.

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"[21].

The integrated SC or supply network, goes beyond the traditional concept of logistics and flow of materials, and emphasizes the need of the interaction between the several actors of the chain during the creation of customer service. The level of service, in fact, as well-known literature shows, is now the focal point in a process of selection and increase; so for developing better performances and for creating value, companies must interact with each other creating organized rows; moreover they must hold an aware common vision, since the inside competences become insufficient in the global-competition [3].

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 to improve them and make faster the flow through chain's levels, [1], [6], [7].

In this endeavour supply chain management is a large container in which inventory & purchases management, capacity management , production planning and scheduling, suppliers monitoring and management, distribution management are present.

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 finished parts, nor 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 has to coordinate the customer's requirements to the supplier deliveries and to the logistic organization flow; it's necessary to realize the customers, suppliers and flow integration.

The "company in the middle" cannot manage all these things if it doesn't realize the internal integration and organization. It goes through the following 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, the changes of customer requirements and the waiting time in queue for WIP first to arrive at the work-station [3].

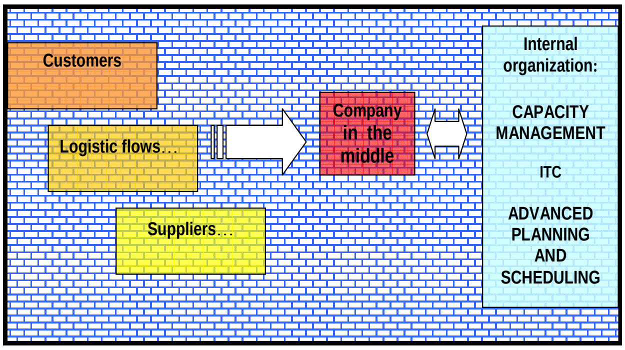


Fig.1 - Company in the middle point of view

2.1 Subsection

The capacity management for APICS dictionary [8] is the function of establishing, measuring, monitoring and adjusting limits or levels of capacity in order to execute all manufacturing schedules: production plan, master production schedule, material requirements plan, and dispatch list.

Capacity management is executed at four levels: resource requirements planning, rough-cut capacity planning, capacity requirements planning and input/output control, see fig.2.

In the long term combined choices must be made on the use and eventual increase of capacity through the increase of productive units; these must be evaluated by RRP and RCCP systems that make an aggregate verification of the system's real possibilities; with the MRP elaboration of the requirements' plan , we obtain the calculation of the load with infinite capacity on productive resources, which allows us to take note of the overloads which are absolutely inadequate for the available capacity.

However it does not take into account the effective availability of the resources.

In fact once the gross needs have been established on the basis of the orders' requirements, and from these through the coefficients of use and the percentage of scraps, having determined net requirements and established lot-sizing policies, MRP establishes the needed quantities, anticipating the production on the basis of the lead-times (presumed).

We are referring to the dispersion of the capacity when ever taken into account, during a preventive evaluation, a plant's capacity and the difficulties existing in measuring this, it is not always meant to obtain the expected theoretical capacity, because of break-down and changes of program, due to staff storage, quality problems, delays in the deliveries of the products necessary for the successive stage of work and so on.

Some of these factors cannot be avoided, as they are ingrained in the sector to which the company

belongs to for technical ties; all this brings about a reduction in the effective usable capacity [7].
The infinite capacity calculation considers every order as if it was the only circulating in the productive areas.
The hours of production of an order are added to the sum of work-hours of the work-centre to which they are destined without taking into account the weight generated by every order on any kind of resources (work-force, machinery, utensils) or the impact of unforeseen events, the delays, scraps and re-fabrications.
At this point the CRP intervenes, finally by discovering the divergence between the foreseen and effective capacity on single resources in the medium and short term.
It must be said that finite capacity CRP modules although allowing detailed planning, do not always allow an effective measurement of the plant's real possibilities, for all the series of variable that characterize a company's life and for the determination of the lead-times [15] that in most cases do not correspond to effective values.
Capacity is generally scarce because, in order to be competitive, fixed costs have been reduced by outsourcing in recent years [9].
In a flexible industrial process, each order involves a different set of jobs in the fabrication and assembly process. The operations involved in a job are interrelated by precedence constraints, and can be effected on alternative machines.
Capacity adjustment is also possible through outsourcing with subcontractors when due dates cannot be kept.
Timely and reliable delivery of products is an important factor in the manufacturing supply chain to ensure that manufacturing companies remain competitive.[2]
The capacity management is aimed at supplying methods and suggestions to establish the total capacity level of productive resources (structures, machines and work-force) that best supports the company's long term competitive strategy.
The chosen capacity level has a substantial impact on the firm, in terms of answer to the customers, structure of costs. In order to face situations in which demand

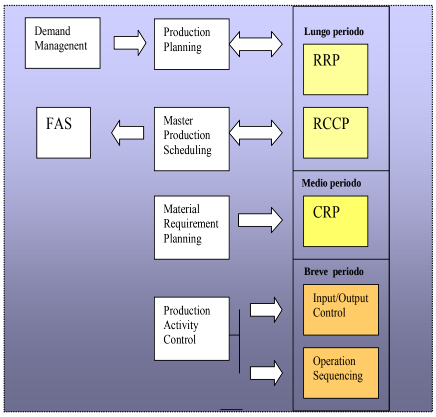


Fig. 2 - Capacity management scheme

exceeds the firm's productive capacity, the decision to increase capacity is not always a good solution, considering the costs and time connected to the consequential investments.
Alternatives must be sought, not so much to modify productive capacity, but rather to improve the exploitation of the available resources [27].
Defining the level of present capacity does in any case imply approximations and estimates, and will therefore always be characterized by a certain margin of uncertainty; the optimal operating level indicates the capacity level for which the process has been planned, it is therefore the volume of output at which the average unit cost is minimized.
Some successes in the solving of scheduling problems with capacity ties on the resources have been obtained by using mathematical formulation with methods of lagrangean relaxation LR (Fischer 1973, Of Cross et al. 1993) or decomposition (Ashour 1967, Chu et al.1992).
In LR methods the ties of precedence and capacity are relaxed using not negatives lagrangian multipliers , whilst the decomposition ways of approaching divide the original problem in a series of minor problems, that are easier to handle, even solvable also in optimal manner.
Murali Sambasivan [28] has elaborated a heuristic lagrangian for lot-sizing multi-plant, multi-article, multi-period problems with transfers between plants which generates "a good" solution.
The authors have developed a procedure that consists in two cyclic phases aiming to remove capacity ties: lot-shifting and lot-splitting.
The success of the lagrangian method depends on the lowest limit given by relaxed problem and by the updating method of lagrangian multipliers.
The method is widely used to solve optimizing problems. The multiplant problem with m plants, in terms of calculation difficulty, is at least as difficult as m single problems on single plant.

Many researchers, amongst which Barany I, Van Roy TJ, Wolsey [29] have tried to solve the lot-sizing, multi-items problem on single plant by trying to obtain a solution very near optimum through a programming algorithm, but they have not succeeded in solving the problem "on large scale", as they have not managed to foresee the number of cut plans to generate, or the number of repetitions that are needed in a B&B method.
An interesting heuristic approach to solve problems on large-scale based on the lagrangian method has been developed by Trigerio et al. [30].
This method has earned the maximum attention for solving qualified lot-sizing problems. The lagrangian relaxation of the capacity ties uses Wagner-Whitin algorithm for each item and this can be solved quite easily to succeed in optimizing.
C.Vercellis [27] has studied a problem of planning and dividing capacity for a manufacturing system in a multi-plant with two phases in series in every plant, considering the cases in which are allowed or not allowed between the two phases.
A particular aspect of the considered system is the possibility of a dynamic auto-configuration when the buffering is not present, in the sense that for every run the parallel machines in the second phase are grouped together and connected in series to a machine in the first phase.
Even if set-up times and costs are not considered important in the model, binary variable are used to calculate the minimum dimension of the lot. The resulting model is resolved by heuristic procedures.

2.2 The Advanced Planning and Scheduling.

There is no guarantee that MRP's elaboration is feasible. 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 behavior 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. [4]
Now it is widely recognized that the process batching involves a convex relationship of lead time as a function of processing batch.
So it exists an optimal solution to minimize lead time , and in the case of a deviation from that, there are substantial problems for high utilization and stocasticity.
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 [5].
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 uses advanced mathematical algorithms or logic to perform optimization or simulation on finite capacity scheduling , sourcing, resource planning, forecasting, demand management and others [8].
These techniques evaluate more constraints and business rules to 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 seen above, 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 the master planning is elaborated and in the short term it needs to be made Purchasing & Material Requirement Planning, Production Planning and scheduling and Distribution & Transport Planning.
The oldest studies on APS are focused primarily on the heuristic approaches. Bahl and Ritzman (1984) proposed an integrated model with an heuristic procedure that decomposes the problem into smaller sub-problems and solves them in an iterative fashion [11].
Nasr and Elsayed (1990) provided two heuristic approaches to minimize the mean flow time in order to have a good schedule for the n jobs/m machines problem [10].
Sum and Hill (1993) presented a framework for manufacturing planning and scheduling Systems formulating an iterative process between the order network and the operation network to quantify lot-sizes and operation schedule [12].
Subsequently Agrawal et al. (1996) took again a precedence network to develop a generate near-optimal schedules by reorganizing relationships among items with an heuristic approach [13].

Mathematical programming has been widely applied in planning and scheduling job-shop problems. Some research workers have approached these problems using linear programming (Balas 1965, 1967), entire mixed programming (Balas 1969, 1970), and dynamics (Srinivasan 1971).
Before these, the use of such techniques was limited because planning problems belong to the class of the NP-complete problems. Furthermore, the improvements in research on this subject have received a strong stimulus from the evolution of computer science technologies and the computing powers.
In 1960 Giffler and Thompson said [31] that linear programs do not lead to practical method of solution whilst French (1982) made the observation that the formulation of an entire programming model of problems scheduling is not feasible from computing point of view [26].
Nemhauser and Wolsey (1988) and Blazewicz et al. (1991) emphasized these difficulties and indicated that linear programming's models have not allowed scheduling programs to be overcome. So that these techniques are suitable for problems of limited difficulty within a reasonable period of time, but mean necessary and consistent simplification.
Taal and Wortmann (1997) described a new scheduling technique to integrate MRP with finite capacity Planning. Kolish (2000) introduced an MIP (mixed entire programming) with a two-level, backward oriented [9], top-down approach model to solve the problem in which the same part type is requested by different customers (lot-sizing decisions) but it only considered a product with two levels, while a real product usually has many levels.
He studied a make-to-order assembly environment in which there are resources, assembly area and part availability constraints.
They used a random sampling method and two taboo search based large step optimization models to minimize the sum of earliness and tardiness penalties, and minimizing the number of late jobs.
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 make span, 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 this model a GA-based approach was developed.
Chen et a. [4] presented a MIP 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 increased 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 entire linear programming model, Capacitated Lot-Sizing Problem with linked Lot-size [16], 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, it makes the various phases to 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 does not give the solution to dynamic problems scheduling and we do not get necessary computing power (NP-hard problem).

2.3 The simulation, a tool of APS.

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.

Often, these are static simulators, that only consider some parameters and do not take into account the real staff availability (due to holidays or leaves), the movements of materials inside the plant, the stochastic nature of many variable of the 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 [5], [18].

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 the 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 [3].

In the stochastic models we can also have as variables in input probability density functions and known probabilistic distributions; meaning that infinite possible histories can be generated with the same combination of situations.

So a real sampling of possible histories can be obtained and with these the main characteristics of system functioning can be evaluated [18].

According to Musselman et al.(2002) “Modern Enterprise Resource Planning (ERP) systems contain all the data necessary for detailed production planning”[19].

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” [19].

The worse defect of ERP system is that the 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 the system, then feeds a scheduler module that produces detailed lists of operations on work-centers.

Then it returns this 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 t on 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[19].

Through 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 it is diffusing the use of simulation as support for 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 [23].
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 identified 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 [20].
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).

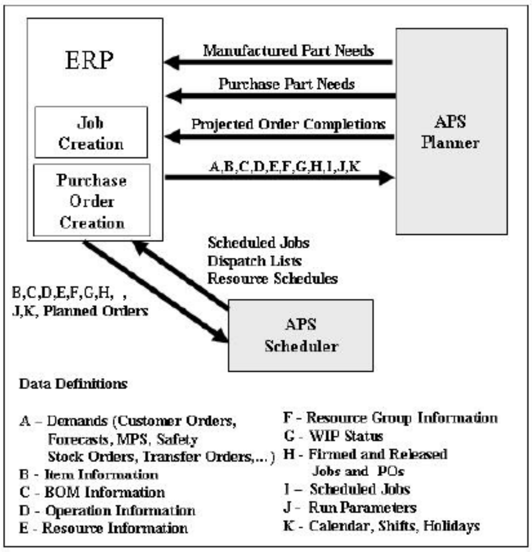


Fig. 3 APS loop.

The Musselman approach, as we have previously seen, of a simulation-based function integrated within ERP, was taken again by Mazziotti and Horne (1997) [24] allowing to make “what-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 Naktani (1998).
Then Marvel et al. (2005) [25]used simulation to validate the capacity planning process as well as generate a feasible schedule for a tier two automobile suppliers. 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 available in literature on the use of simulation models as a tool to improve the performance of a system.
Alan et al. [21] proposed a simulation model to reveal the critical elements of the system and relationship with the system to improve the process performance .
This is a case in which simulation is a tool to redesign the production process.
A more complete system was proposed by Kuhen et al. (2004) for job-shop processes [22]. The authors developed an integrate system to support production planning and control by the employment of Java and database applications (Simulation Based Job Shop Analyser).
It enables the modelling and simulation of the operations for a any job-shop system, and allows the maximum on flexibility and robustness giving a fully automated generation of the actual simulation model by use of production data from the database ERP.

3 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, the necessary processings are modelled using PROCESS blocks.

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 many processing can be made. So within a STATION there will be a set of SEIZE, PROCESS and RELEASE blocks.

Using a database it can defined the resources needed for processing, the technological sequence and the processing assigned to a station.

This approach allows 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:

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

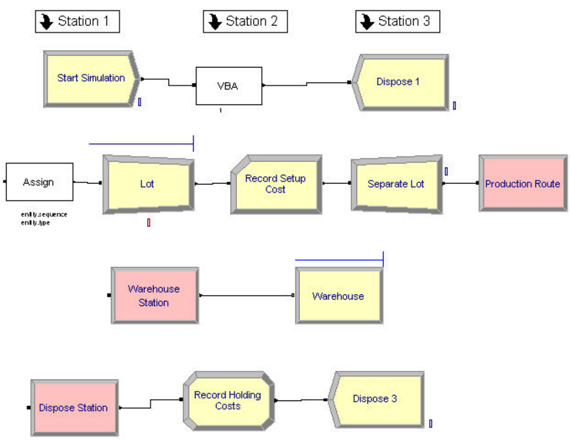
Table 1. Operations

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

Before the simulation runs, the simulation model is customized according to database information about technological cycle, resources available.

Figure 4 shows on the top 3 sub-models that collect the activities of Station 1, Station 2 and Station 3 respectively.

Figures 5, 6 and 7 show the activities in the sub-model Station 1, Station 2 and Station 3.



FiFig. 4. Simulation Model

In each sub-model, there are 2 fictitious activities that seize/release resources needed for processing, however, other activities are processes.

Figure 4 shows, after the sub-models, a VBA (Visual Basic for Application) Block that allows reading from the database all the information needed for the simulation. The information in the database are the status of the system in terms of work in process, the production orders and the processing time.

After the creation of the job, each job of an order are batched. So the system record the setup cost and then the order follows the production sequence.

When the process ends, the products are routed into the warehouse.

When the products are delivered, the system evaluates the holding costs.

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

- forwards
- backwards

In the first one, according to a scheduling provided to the simulator, it can be assessed how many products are available in different periods.

In the second one, through an optimization model the quantity to be produced in different periods is set depending on products demand and respecting some constraints.

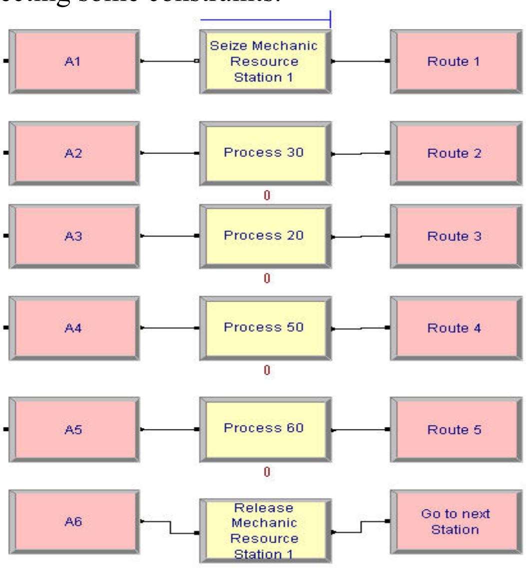


Fig. 5. Sub-Model Station 1

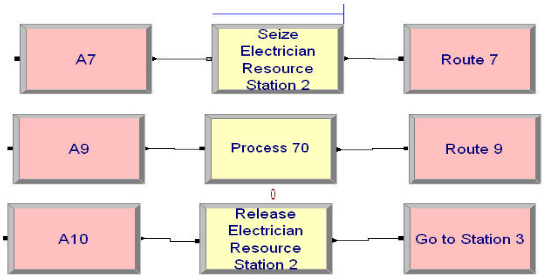


Fig.6. Sub Model Station 2

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.

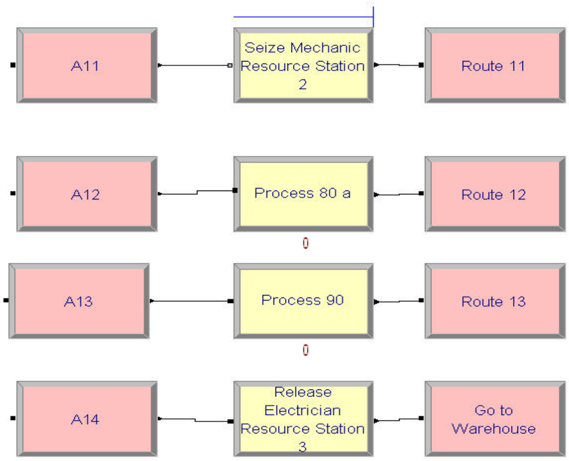


Fig.7. Sub Model Station 3

Station	# Processing	Average Processing time (min)	Standard deviation
Station 1	30	70	4,25
	20	52	6,27
	50	29	3,01
	60	25	1,70
Station 2	70	130	
Station 3	90	*120*	***8,57***
	80	*75*	***2,36***

Table 2. Technological cycles

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]:

$$\text{Min! } \Sigma_{j=1..J} \Sigma_{t=1..T} [h_j \cdot I_{jt}] + \Sigma_{j=1..J} \Sigma_{t=1..T} [sc_j \cdot (Y_{jt})] \quad (1)$$

subject to:

$$\Sigma_{j=1..J} \Sigma_{t=1..T} IR_{jt}=0 \quad (2)$$

$$\Sigma_{j=1..J} \Sigma_{t=1..T} X_{jt}>=1 \quad (3)$$

$$\Sigma_{\tau=1..t} X_{j\tau} >= \Sigma_{\tau=1..t} P_{j\tau} \quad \forall j \in 1..J \quad \forall t \in 1..T-1 \quad (4)$$

$$\Sigma_{t=1..T} X_{jt} <= \Sigma_{t=1..T} P_{jt} \quad \forall j \in 1..J \quad (5)$$

$$X_{jt} \in N \quad (6)$$

Where:

h_j : Holding costs for a unit of item j in a period ;

sc_j : Setup costs for a lot of item j;

I_{jt} : 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;

The equation (1) is the objective function. This function minimizes the total costs (holding costs and setup costs).

The equation (2) is a constraint that allows to obtain only solutions without backlog.

The equations (3) ,(4), (5), (6) are constraints that help the optimizer to investigate only a sub-domain of meaningful solutions.

This model optimization is generated automatically based on the parameters of the database.

The software OptQuest for ARENA perform optimization by the model generated.

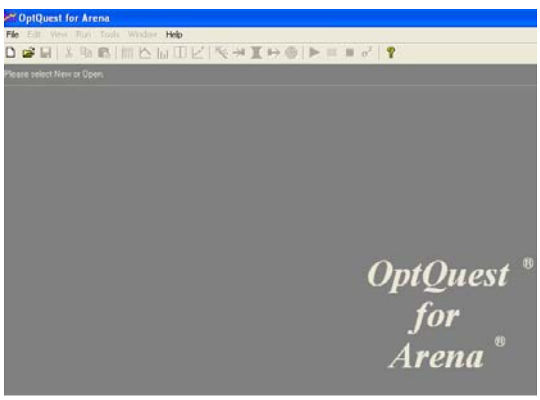


Fig. 8. Arena OptQuest

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