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An approach for the evaluation of an integrated process and production planning and control system

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Abstract

This paper presents a research project under development, aiming to integrate Production Planning and Control functions and Process Planning functions with the support of a Discrete Event Simulation tool. This integrated system will be targeted to typical metalworking companies, manufacturing small to medium sized batches. Planning and control of large production systems involves the resolution of very difficult problems, normally demanding a high degree of human intervention. Through this approach we aim to improve the effectiveness of each planning function and also to simplify the decision-making tasks when dealing with unexpected events at shop floor level.

Keywords

Process Planning, Production Planning and Control and Discrete Event Simulation.

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1 INTRODUCTION

New challenges are forcing companies to improve manufacturing system performance in order to maintain their competitiveness. A more demanding requirement for new and more complex products has been forcing the companies to concentrate in reducing, both, the design and manufacturing cycle time. Customer satisfaction is a key objective. Consequently, flexibility, quality, cost and on-time delivery are the main requirements in the design and management of the overall manufacturing system. According to the type of manufacturing process (from mass to job-shop production) the use of Advanced Manufacturing Technology offers new chances in the level of integration and in new approaches for the implemented operational strategies. With the development and the spread of the CIM concept, the need for the integration of an increasing number of functions was established. Many specialized methods and procedures were developed, enabling each individual system to work more effectively with data generated from the different functions.

Manufacturing planning decisions are made on different phases of the product and process development cycle, such as process planning, master production scheduling, capacity planning and production order scheduling. In fact, the integration of planning functions has been referred to as a key issue in state-of-art manufacturing systems. Particularly, Process and Production Planning, which are two multi-task activities of particular importance in the batch manufacturing environment, are the candidates for the integration effort. In this type of production system the number and the variety of products to be manufactured will have influence in the chosen technology together with the management approaches used. Process and Production Planning integration will result in shorter lead-times, more efficient manufacturing systems and a high competitive advantage (ElSayed, 1996).

2 REASONS FOR THE INTEGRATION OF PROCESS AND PRODUCTION PLANNING

Integration of Process and Production Planning is an approach that enables each system to function more effectively, especially in organizations where production-to-order is dominant or an increasing number of different parts, to be manufactured in lower lot sizes, is required. Any production system is characterized by a set of technologies and organization structures which is determined by the diversity of products that they are able to manufacture and the expected demand. Additional strategic decisions should be done setting the manufacturing facilities (e.g., equipment and layout) and the operational strategies, such as lot sizes and workflow, to couple the customer orders.

The rapidly changing situations that happen in real manufacturing environments, involving some aspects like materials availability, order due dates/lot sizes, route sheets, lead times and manufacturing resources, result in difficulties in carrying out the daily plan. The competitiveness of each manufacturing system will be dependent on the capability to manage the dynamic changes that will occur during a normal run. As an example, many causes can be identified which influence the delivery time. The Cause-and-Effect diagram as shown in Figure 1 provides a structured view of the disturbing influences on on-time deliveries, guiding manufacturing managers on the definition of strategies for continuous improvements.

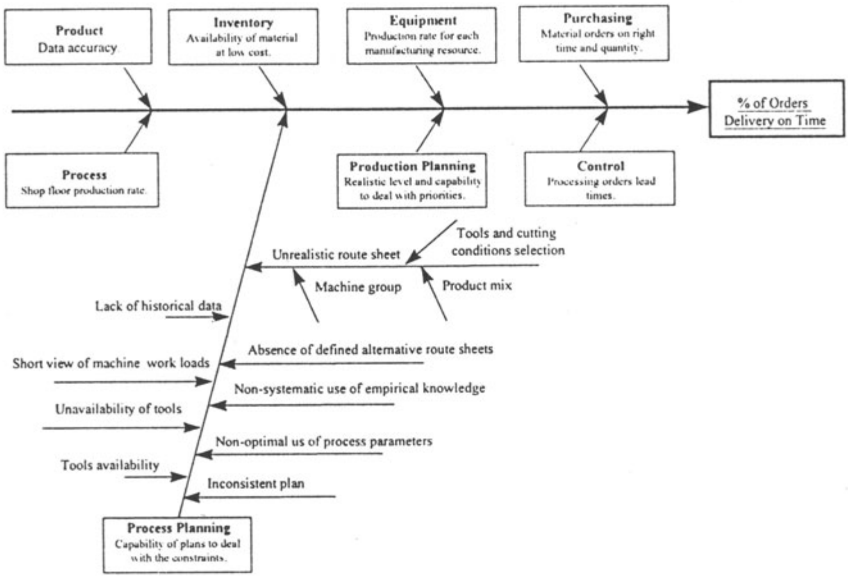

Figure 1 Example of using Cause-and-Effect diagram for the analysis of the process planning task

Process planning as a stand-alone function does not consider the *available* resources at the shop floor. An event in the shop floor, such as bottlenecks, unavailability of tools and equipment breakdown, influences the execution of the manufacturing orders. In this case available pre-developed process plans are no longer adequate. The common procedure is to change the process plan at the shop floor, which can result in an inefficient (non-optimal) plan or the need for the utilization of alternative sequences of operations and resources. So, the process plan or route sheet, as a static and linear sequence of operations, does not cope with the shop-floor dynamic behavior. Process planning must be carried out considering the specific machine and tooling capacities, determined by the parts to be manufactured, on an underlying dynamic shop-floor scenario. The real scenario in manufacturing environments includes simultaneous in progress work, sharing finite resources, scheduled works and unexpected events that affect the production capacity. Process planning systems must interact, in this context, with shop floor scheduling and monitoring systems, recognizing the actual conditions and modifying the production plan, using alternative and "optimal" process plans. These difficulties are amplified by the lack of ability that the manufacturing planning and control systems have to operate with the process plan. The ability to communicate effectively between each system allow to create process plans dedicated to problematic situations (Cunha, 1996).

Considering the above mentioned events, the absence of materials or any changes in orders or route sheets, requires that some changes have to be proposed by shop-floor managers or schedulers, in most of the cases based in their empirical knowledge of the manufacturing system. This traditional approach requires that very skilled managers have to be involved in this level of decision. The influence of such decisions sometimes can be seen in an increasing level of entropy due to the resources that are shared and the clear competition between each order in reach of their operational objectives.

From our own experience, other topics can be presented, showing some weakness in the traditional approach to deal with Process and Production Planning tasks to run the manufacturing process. These can be summarized in the following:

a. Most of manufacturing planning and control systems do not include facilities to allow an efficient visibility of existing problems, as a support for an optimization of manufacturing resources;
b. Operational managers in general don't have enough data to deal with the increasing complexity of decisions required to manage the manufacturing process;
c. It is usual to observe a lack of data aggregation, processing and understanding at shop-floor level;
d. It is common the low level of quality, accuracy and effectiveness of feed-back data from shop-floor;
e. There are no guarantees for an uniform use of resources, meeting the due dates and working at minimum cost;
f. Limited capacity to answer to "what...if...?" questions, specially of a fuzzy pattern;
g. Most of the decisions in managing the manufacturing process are based on an empirical knowledge of the system;
h. The way that the lead times are defined does not guarantee validity and introduce difficulties to meet the due dates;
i. The traditional approach does not allow a dynamic scheduling of events, which should be done according to the real manufacturing environment;
j. Changes in due dates in an open order, involve a sequence of procedures within the company where it is difficult to find out which actions should be taken, specifying clearly when and how each operational staff should act.

3 INTEGRATION OF PROCESS AND PRODUCTION PLANNING

State-of-art computer aided Process Planning (CAPP) systems support the main functionalities that are required for the work planning in the production process. The capabilities include the creation of process plans, the design of raw materials, the selection of operation sequences, machine-tools, cutting tools, fixtures and machining parameters as well as the determination of manufacturing times. All technically feasible manufacturing routings and the necessary manufacturing resources are described and can be made available. CAPP systems for generating process plans operate based on data that are related to the customer order, manufacturing and technical know-how and an appropriate planning logic. Some systems retrieve existing process plans assigned to particular part families and allow the revision of these existing plans to develop new ones (variant process planning). In other systems, a new process plan is generated for every part, based on the description of part geometry and other part characteristics, through the application of a particular manufacturing logic coded into a suitable computer program. According to Kuhnle (1994) most of the available systems on the market are technologically oriented, rule-, or knowledge-based systems. They operate semi-automatically based on data that is related to the customer orders, manufacturing and technical know-how and an appropriate planning logic.

Production Planning and Control (PPC) systems are responsible for planning the utilization of production resources (e.g., machines capacities, labor, production quantities), which are required to satisfy some performance criteria, over some planning horizon, within some demand pattern. PPC systems are based on a description of the product, a description of the necessary operations, required production resources and dynamic information (e.g. varying with time) with regard to demand and the availability of resources. The complete scheduling and controlling of the production process are performed within the PPC system allowing a vertical integration of some planning tasks (e.g. from upper levels of decision to operational level). From master scheduling to material and capacity planning, order quantities and timing for placing orders are determined. At different time scales, schedules are produced with the aim to co-ordinate the necessary resources to fulfill production orders. Figure 2 shows the time scales and different planning time-horizons identified in Process and Production Planning and Control systems.

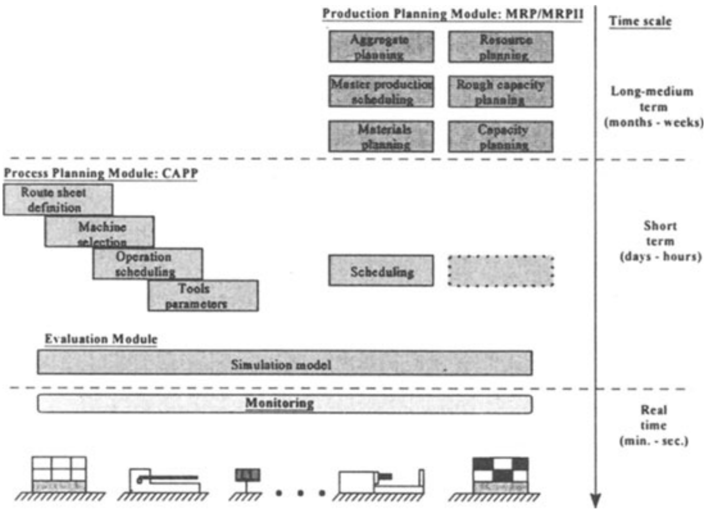

Figure 2 Time scale associated with different functions with the PPP-Integrated Approach.

Planning objectives, manufacturing resources and performance measures or decision variables should be shared between the Process and Production planning tasks. Such an assumption yields a good foundation for integrating those tasks in a single multi-objective planning system (Elwany, 1996). Synergies can be generated from changing the traditional and non-integrated use of those systems into collaborative tasks, where advantages are obtained from the functions performed by each system together with the shared use of information.

The integration or collaboration of process planning and production planning, through the scheduling function, has been the focus of some work in recent years. The objective to implement dynamic Process Planning systems, has been presented through the developments of links between a CAPP system and Production Planning (scheduling), where three basic research approaches are being followed: non-linear process planning, closed loop process planning and distributed process planning (Wiendahl 1995, Leung, 1996).

CAPP and PPC systems are both modeling a part of the manufacturing process. From this manufacturing model, planning of production flow and employment of resources is required in order to assess manufacturing system performance. Process planning systems still rely on a *static* understanding of the plant. They are process dependent but time invariant functions. On the other hand, Production Planning and Control systems are both, process and time oriented and they lead to the use a *dynamic* view of the production process. The common element between both components is represented today by the process plan, which can be made available to the PPC system from the CAPP system by means of a data interface (Kuhnle, 1994).

As it has been pointed out, in the integration of CAPP with scheduling, some of the key aspects in this link are the choice of an optimal route, the determination of cycle and set-up times and the dependency of process planning on the loading conditions. However, the existence of a set of random events that occur in the real manufacturing environment, doesn't allow getting optimal solutions but searching for better alternatives. Discrete Events Simulation (DES) system by itself has an important role in dealing with stochastic systems allowing the representation of that randomness. Also, through the simulation, a set of equipment, labor and other facilities can be built into a model. This kind of system can easily allow the evaluation of produced schedules closer to a real scenario. Different process plans can be tested trying to reduce the effect of shop floor unexpected occurrences. Simulation can also provide managers with both qualitative and quantitative data on the effects of real-time constraints on the manufacturing system performance for decision making. Its facilities can minimize the lack of confidence in the expected results when a specific strategy is implemented, which has been a restriction for an effective management system. Through DES, a model of the manufacturing process can be developed and analyzed, generating data for decision making. Figure 3 illustrates the concept for CAPP/PPC/DES functional link.

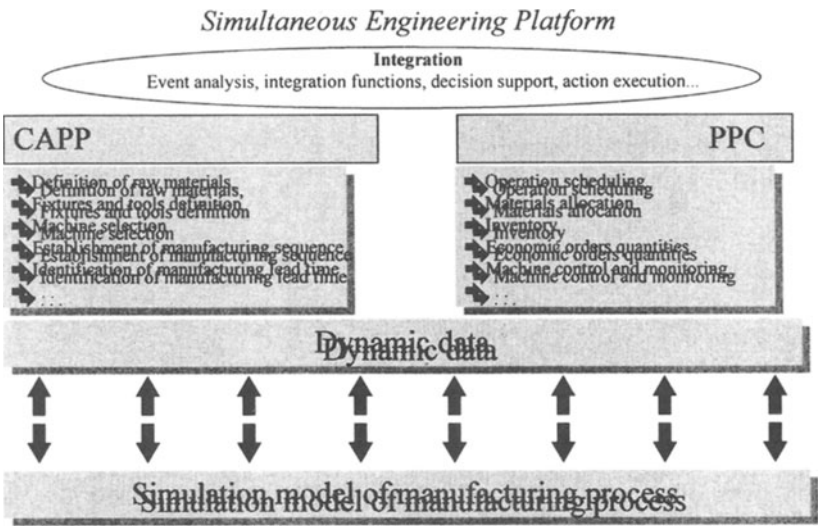

Figure 3 Functional use of PPC, CAPP and DES techniques.

In the proposed architecture, commercial software packages are being used. A variant CAPP system, an MRP/MRPII system and a graphical simulation tool were selected. Our main purpose, in this selection, was to use the software applications that were compatible with the tools and methodologies used by Portuguese batch manufacturing companies. These applications are the core of each module identified in our proposed architecture (Figure 4).

As an interface approach a production relational database (RDB) platform will be used to link the different applications. In the RDB exist different folders with product and process-oriented data as well as the time and event-dependent data collected from shop-floor behavior. A shop-floor control system (SFC) can implement the required monitoring functions allowing the gathering of on-time and accurate data to be used in the evaluation of manufacturing system performance, as well as in the re-scheduling function. This database will be used to share data between each system and function. The RDB will allow the production scheduler to produce new alternative plans taking into account the status of the shop floor. In this integrated environment it is possible to develop and maintain effective schedules of manufacturing orders.

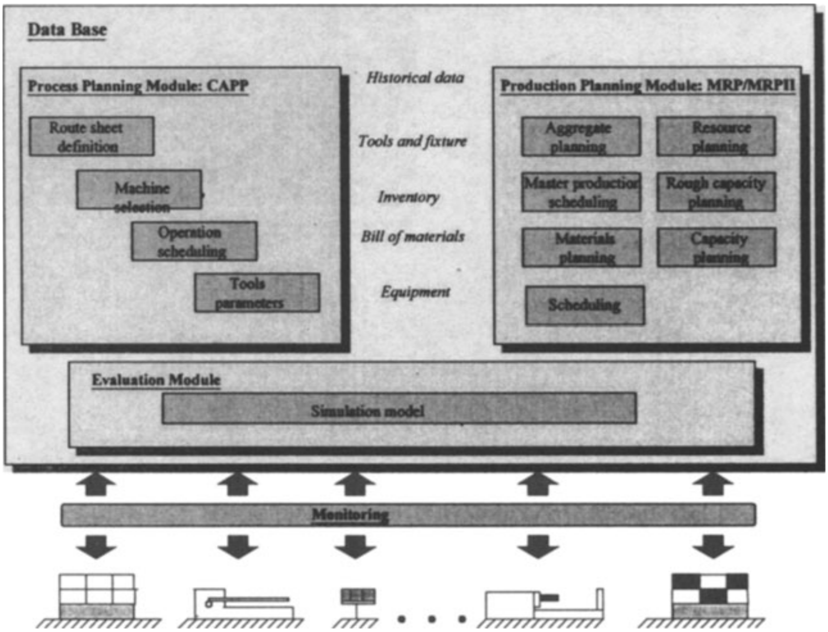

Figure 4 Functional architecture for an integrated Process and Production Planning and Control system.

The functional architecture presented permits potential links to be established between each function. It includes not only the Process Planning - Production Planning link, but also the Process Planning - Capacity Planning and Process Planning - Shop Floor Control integration.

Figure 5, presents some of the commercial tools that are being used in our integrated approach. At this stage of development, work has been done on the integration of a CAPP system (MetCAPP/1 from IAMS) with the simulation system WITNESS (AT&T – ISTEL). For a given set of parts to be processed in our manufacturing system, a model is defined in the simulation system. The CAPP system generates the sequence of operations to be carried out at each workstation (in the future the alternative process plans will be generated also by the CAPP system). The integrated system approach allows that every new set of route plans, cycle and set-up times, when required, will be delivered to the simulation system. At this moment the alternative route sheets are defined in the simulation model but it should be transferred for the planning task.

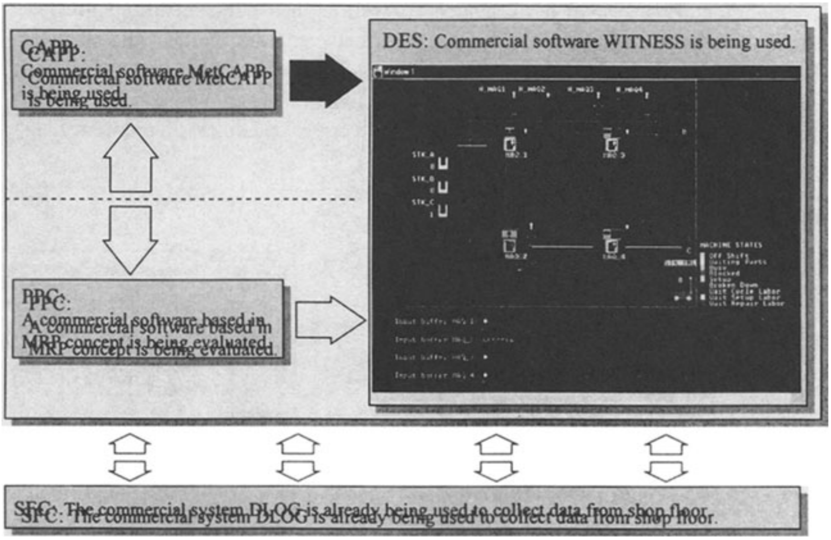

Figure 5 Experimental use of integrated Process and Production Planning functions

In our approach, we focused our integration effort in short-term to real-time scales, e.g. the operational level. Here the monitoring requires the existence of a Shop Floor Control (SFC) system for an effective data collection. The feedback of data to the integrated Process and Production Planning and Control system should be based on measures (e.g. variables) which allow the scheduler or any other user to evaluate the performance of the manufacturing system. The performance measures also allow communicating up to each level of the integrated system on the manufacturing system behavior. The CAPP, PPC/SFC and DES systems are the backbone that integrates vertically up and down the company organization chart and horizontally across functions. At each level of decision making, the evaluation of different strategic and/or operational objectives is required. Consequently, several specifically designed performance measures are required for evaluation and for guiding the management of the manufacturing process.

3 DEVELOPMENT OF THE EVALUATION MODULE

The evaluation module has core relevance in the presented architecture. Having access to the collected data from the shop-floor we plan that this module will evaluate the operational performance of shop floor and test the effectiveness and reliability of process and production planning, whenever they are used to run the manufacturing process. The evaluation module should be flexible enough to assess the capability of each individual function or the overall system in dealing with unexpected events. In Figure 6 it is possible to observe some of the facilities planned for the evaluation module.

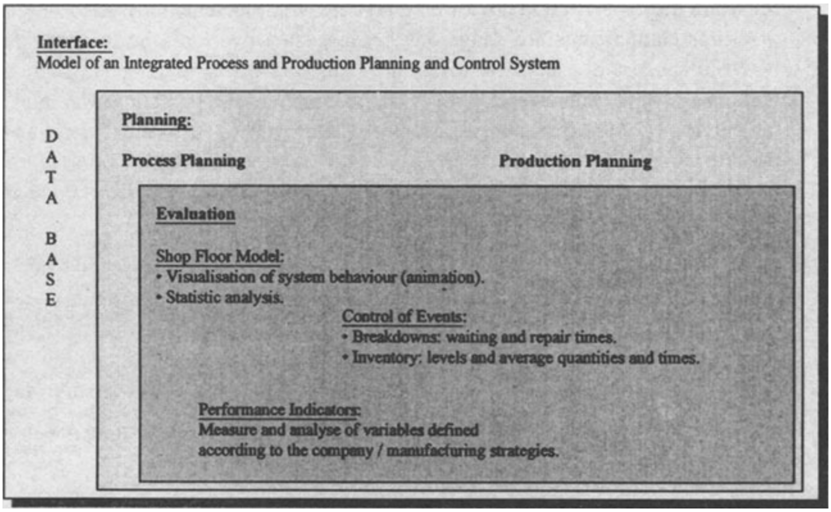

Figure 6 Evaluation module in an integrated Process and Production Planning and Control system environment.

The use of Discrete Event Simulation in the evaluation module as well as statistical analysis tools is supported by the understanding that the efficient management of the manufacturing system requires system performance prediction rather than system failure or malfunction assessment after the occurrence of problems. The effective use of simulation requires that a validated model of the manufacturing process be built. Its animation capabilities will help to observe and understand the results of each simulation run. Also the model can always be updated with data that is being collected from the shop floor, allowing a better confidence on the results of the simulation. For an effective data processing and statistical analysis, in the implementation of the evaluation module, an effective link with the shop floor control system will be required. This system should allow observing in real time the value of some shop floor events. Those events can determine a set of performance measures to be used in the evaluation of the manufacturing system behavior.

Performance measures are interrelated throughout the organization. They should be implemented in order to articulate company strategies and monitoring the business results. The linkage between the established strategy and of required performance measures becomes very important as performance measures are pushed down the organization (Grady, 1991). Operational and tactical decision making without regard to strategy can be very costly and can result in a non-competitive position. In spite of already existing methodologies for defining performance measures we believe that its consistency with strategies are not achieved easily (e.g. they need to be linked to ensure they support and do not inhibit strategy implementation). Also single measures comparisons are dangerous because they overlook the interactions between specific objectives at different levels of the organization. In such a complex system, characterized by a large number of interacting variables, which are related with many different manufacturing activities, decision-making can result in the establishment of conflicting goals. Figure 7 presents a set of objectives, performance measures and event types that can be defined at each level of the hierarchical organization of a company.

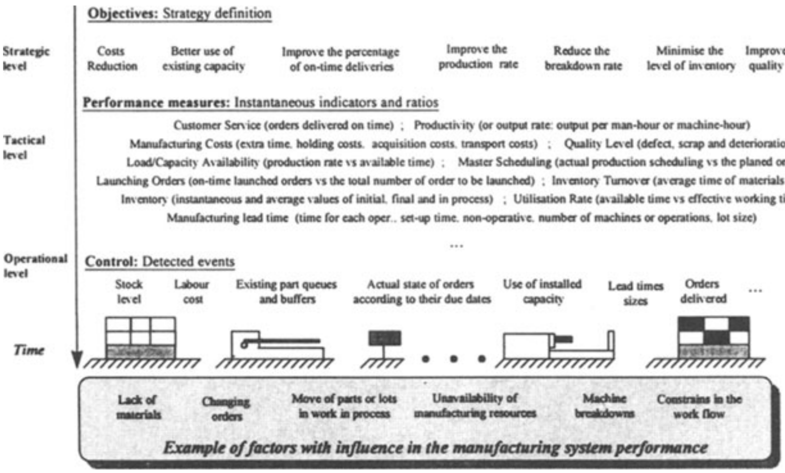

Figure 7 Levels of decision making within a manufacturing environment.

When we consider the difficulties presented above, we propose a new approach to define the performance measures, in order to avoid loosing the information that exists in each performance measure. This approach is still under development requiring further validation.

The following study has the objective to test the possibility of reducing the amount of data for decision making, without losing relevant information about the manufacturing process. This data reduction is based on a set of new variables that are defined from the initial set of manufacturing variables. The technique used is know as Principal Components Technique and is considered to be a part of Multivariate Statistics.

The study was applied on a simulation model of a typical batch manufacturing company, for which we defined the following variables:

- TEMP.EXEC - Time required to manufacture the total demand of parts;
- OUTPUT - Number of parts manufactured without defects;
- AVWIP - Average number of parts in process;
- AVTIME_A, AVTIME_B, AVTIME_C - Average time the part **A**, **B** and **C** spent in process;
- P_MBUSY, P_MSETUP - Percentage of time the machines were occupied and in set-up;
- P_MBLOCK, P_MREPAIR - Percentage of time the machines were blocked and in repair;
- P_DEFEITOS - Percentage of part defects;
- OCUP.M.O. - Labor utilization rate.

Using the simulation system, the company model was built with the following characteristics:

- *Machines* - A set of 4 machines (resources), each with an input buffer of limited capacity, was considered. The operations executed for each part type in each machine, has a specific cycle time and set-up time. The resources are subjected to failures, which are characterized by the mean time between failures (MTBF) and the mean time to repair (MTTR).

- *Parts* - A set of 3 types of parts was assumed to be possible to manufacture with the existing facilities. For the completion of each part a given number and a pre-determined sequence of operations are required. For each part, a percentage of defects was defined at the end of the process as well as when each failure occurs. Every part type has a demand value, however we assumed that in each simulation run a total demand of 300 units exists.

- *Labors* - A set of 4 human resources required for the machines set-up and operation was defined. The allocation of each human resource to the machines was changed influencing the times for those operations.

Due to the necessity to have a sample of significant size we planned 100 experiments (e.g. simulation runs). In each experiment, we change the initial condition of the model, such as the part mix, the launch sequence, the cycle and set-up times and labor allocation, machine failure and part defect rates. Table 1 presents the results obtained from the simulation run.

Table 1 Part of data matrix

n	temp.exe	output	avwip	avtime_a	avtime_b	avtime_c	p_mbusy	p_defeit	ocup.m.o
1	1471,7	288	151,9	745	0	0	73	4	75
2	1337,8	235	149	664,3	0	0	73,3	21,7	76,5
3	1123	183	148,1	554,5	0	0	76,7	39	79,1
4	1036,4	137	151,3	522,6	0	0	74,9	54,3	79,3
5	900,93	102	150,39	451,65	0	0	78	66	79,4
6	1478,4	293	150,1	0	739,5	0	43,4	2,3	44,5
7	1370,5	262	152,9	0	698,7	0	44,9	12,7	46,6
8	1253	232	151,8	0	634	0	47,3	22,7	48,2
9	1212,3	204	151,8	0	613,4	0	47	32	49,3
10	1156,7	179	153,7	0	592,8	0	47,2	40,3	49,2
...	...	...	...	...	...	...	...	...	...

n - Experiment number.

With the data matrix obtained from the simulation (Table 1) the Principal Components technique was used to reduce the dimensionality of data. Using this technique a new data matrix was obtained (Table 2) with the contribution of the initial variables for the principal components. Each principal component (*comp.i*) corresponds to a new variable. Based on the theory of Principal Component technique more than 80% of the information is in the first four principal components. Consequently we have reduced the number of variables to be dealt with.

Table 2 Contribution of variables for the principal components.

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5	Comp.6
AVTIME_A	0,38887	0,83217	0,05313	0,21388	0,2054	0,04897
AVTIME_B	0,1064	0,09589	0,08182	-0,05257	0,02328	0,27666
AVTIME_C	0,42941	0,5892	0,04627	0,06729	0,19344	0,02789
AVWIP	-0,11326	0,89371	0,0571	0,20611	0,14323	0,1664
OCUP.M.O	-0,05517	0,25755	-0,04437	0,94372	0,17384	-0,06087
OUTPUT	-0,30915	-0,51575	0,71503	-0,04588	-0,22383	-0,06024
P_DEFEIT	-0,21602	-0,22828	-0,93926	0,0212	-0,02179	-0,06313
P_MBLOCK	0,09262	0,13039	0,02993	-0,05673	-0,03391	0,94476
P_MBUSY	-0,8896	-0,13883	0,09015	0,26088	-0,25022	-0,05759
P_MSETUP	0,80032	0,42493	0,07227	0,30547	-0,07135	0,04532
P_REPAIR	0,27192	0,25663	-0,06938	0,19678	0,89852	-0,04143
TEMP.EXE	0,95403	-0,05647	0,13209	-0,0206	0,17886	0,06631
	Comp.7	Comp.8	Comp.9	Comp.10	Comp.11	Comp.12
AVTIME_A	0,04121	-0,03659	0,2407	-0,02965	0,03348	0,01174
AVTIME_B	0,94465	0,02379	-0,00129	0,00198	0,00143	-0,00148
AVTIME_C	0,05572	0,6483	-0,00685	0,00779	-0,00885	-0,00165
AVWIP	0,13159	0,21045	-0,17342	0,03914	-0,03163	-0,01729
OCUP.M.O	-0,05693	0,02885	0,00348	0,00605	-0,00174	0,00157
OUTPUT	0,06576	-0,09118	0,04116	-0,01337	0,23822	0,00838
P_DEFEIT	-0,06347	-0,05826	0,01317	-0,00735	0,08032	-0,00061
P_MBLOCK	0,27637	0,01371	-0,0012	0,00154	-0,00342	-0,00039
P_MBUSY	-0,12351	-0,10313	0,06008	0,0006	0,03946	0,12717
P_MSETUP	0,05055	0,10947	-0,03622	0,23923	-0,01278	-0,00173
P_REPAIR	0,02473	0,08301	0,00463	-0,00495	-0,00801	-0,00048
TEMP.EXE	0,0302	0,04987	0,08992	-0,10622	0,01046	0,0975

Our understanding of the meaning of these four new variables is presented in table 3. In this Table, only the initial variables with a larger contribution for the new ones are presented.

Table 3 Summary of results based on the Principal Components technique.

Principal Components	Initial Variables	New Meaning
Comp.1	TEMP.EXE, P_MBUSY and P_MSETUP	Process effectiveness
Comp.2	AVWIP, AVTIME_A and AVTIME_C	Material flow constraint
Comp.3	P_DEFEITOS and OUTPUT	Amount produced
Comp.4	OCUP.M.O.	Labor utilization

These new variables contain all the relevant information about the behaviour of the manufacturing system and should be considered as the decision-making variables.

Further steps have to be carried out for the validation of the use of the Principal Components Technique as well as for the establishment of a set of criteria for comparing performance measures.

4. CONCLUSIONS

The architecture of an integrated Process Planning, Production Planning and Control system was presented. The integrated system makes use of several manufacturing functions enabling the conditions to effectively manage the whole manufacturing system. Minimizing the manufacturing costs, reducing the lead times and improving system flexibility were the targeted objectives.

The approach that was implemented aimed at avoiding rushing orders and the guesswork usually required when the pre-defined route sheets and production plans are to be changed due to unexpected events. The use of DES linked to the Process and Production Planning system allowed the generation of several manufacturing scenarios closely related with the actual shop-floor behavior, since the appropriate linkage with a control system was established. The possibility to know in advance the performance of the system through the use of the results of the simulation run, allowed the analysis of several manufacturing alternatives (e.g. new production schedules), before the proposed changes are implemented.

Simulation tools showed to be very efficient as a data generator, supporting the development of other statistical analyses. The use of new variables as a performance measure was briefly presented. The approach that uses the Principal Components technique needs to be further validated.

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