



NON-DETERMINISTIC DYNAMIC JOB SHOP PROGRAMMING METHOD

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Abstract

This paper explores characteristics of virtual cellular manufacturing systems, of scheduling and dispatching techniques for real time requirements and genetic algorithms for assures a high level of routing flexibility and efficiency in tasks programming for (NDJSP – non-deterministic dynamic job shop problem) systems. It introduces a programming method based in two new clustering and scheduling/dispatching techniques, respectively, applied in NDSJP manufacturing systems. Initially, the work presents basic concepts considered in the organization of cellular manufacturing systems; an approach of virtual manufacturing cells through the functional organization; the characteristics, definitions and notation used for scheduling problems; the description of more manufacturing systems scheduling and dispatching techniques; relevant aspects of evolutionary computation in specialty, the genetic algorithms. Subsequently, the work also introduces the new clustering and scheduling/dispatching techniques, the requirements and the formulas associated. The applications of the two new techniques are exemplified based on two examples picked from scientific literature and so simulated through new software called (DEVICE – Design of virtual cells). The software DEVICE was designed specialty for this research. After run more simulations, the results are obtained in a specialty structured framework. The results obtained for the proposed method application proves the powerful of this approach.

Introduction

The manufacturing system class to be approached in this work is the job shop. Accordingly with Oliveira (2002), the traditional job shop is characterized by permitting many ways of production orders flowing among machines, into the environment constituted by multiple processes and multiple processing resources. It could be said a production manner where many pieces to be produced crosses through the manufacturing system and overlaps could be present, in other words, it do not have the same sequences and the recycles are possible.

Also, Oliveira (2002) says that this organization presents the inconvenient with the high rations of material moving through the shop floor. In this context, going to obtaining alternative processes routings to manufacturing processes executing, the complexity of the system to be planned and controlled is increased too. Sun et al (2002) say that the productivity in this kind of organization has a direct relation with the efficient use of resources, and also, with the capacity of using processes alternative routings. This point of view depends on realizes resources and processes control levels and the execute plan capacities.

According to Seixas Filho (2004), with the market changes characteristics occurring from stable and homogeneous markets to a new paradigm of market with demand characteristics that requires more industry agility to attend consumer needful, the necessity to focuses on a major variety of features and customization of products emerges, jointly with the necessity of guarantee the capacity of supplying consumer orders. So, in this case, the essential characteristics of job shop are: alternative processes routing utilization, resources using frequency increasing to use the biggest capacity of the shop floor as possible, shortest production throughput, shortest costs, quality guarantee and rapid answer to consumers (due data and delivery speed).

In this scenario, the industry can choose among four approaches presented by Goulart (2000), conform the demand environment:

- Make to Stock (MTS): characterized by systems that produces standardized products, mainly based in demand previsions;
- Assemble to order (ATO): characterized by systems that the sets of big components and several materials are stored until the costumer order receiving. The costumer order contains the specifications of final product that are assembled;
- Make to order (MTO): the basic design can be developed based on initial contacts with the costumers. But, the production step is started after a formal order receiving. The interactions with the costumers are almost always extensive, and the product is subjected to the modifications exactly during the production stage;
- Engineering to order (ETO): it is practically an extension of MTO. With the design of product being made almost that total based on customer specifications.

With these approaches, it is clear to see the importance of adequate production process against industry positioning at certain markets, to aim competitiveness advantages against concurrency increasing. In this research it is approached just the ordering oriented systems, respectively ATO, MTO and ETO.



The production capacity, being able itself to choose between some alternatives of process routings, that must be used with a competitiveness weapon, cannot be neglected for the industries, being needful therefore, making decisions in the production time, in strategically way (CHAN, 2003). Actually, there are few references to the use of alternative routings effectively. The majority of these references use a unique routing at the end, and that is considered the optimal routing. In this paper, the strategy adopted makes use of alternative routings for the processes, really.

The production strategy is defined based on establishment and prioritization of competitiveness criteria, with internal and external coherence, aiming always to connect manufacturing operational activities with the industry major goals. Accordingly Corrêa; Gianesi; Caon (2001), the competitiveness criteria provides the following advantages: minor costs; increasing of product quality; high speed of delivery; products delivered in due date (trustworthiness); routings flexibility, or either, to be able to change rapidly the process routings.

The cause of the majority of the actual job shop systems problems can be pointed by the control architectures used, which they do not possess adequate dynamical characteristics to reflect in the shop floor these necessities. Other thing is the existing gap between planning and control layers. Currently it comes being filled for manufacturing execution systems (MES).

Really, the production is an activity continuously executed, in the sense that the jobs come in at job shop on batches. Thus, the nature of production programming is much more dynamic than static. In a job shop called dynamic, the jobs are not available in batches during the programming process. In a dynamic job shop, the jobs come in randomly at the shop floor.

When the jobs come in times are previously knew, there is a job programming problem in a deterministic dynamic job shop. However, in a real job shop environment, the come in of a job correspond to a randomly event (stochastic event). So, it is not knew, a priori, the arrival instants of time to the jobs and nor the machine operations sequences for these jobs. Therefore, the production programming is not deterministic and defines an open time horizon scheduling (time indeterminism). Everything this characterizes the problem of tasks scheduling in a non-deterministic dynamic job shop problem.

As follow, the five characteristics desired for NDJSP systems are described, which foresee the adoption of virtual manufacturing cells. They are:

- **Reconfiguration:** Through the possibility of formation of new logical arrangements of processes routings and resources groupings for virtual manufacturing cells formation process;
- **Customization:** Possibility to work with the production of personalized products, inside of the basic types of demand to be contemplated in this research, ACT, MTO and ETO;
- **Flexibility of process routings:** Capacity to work with alternative process routings;
- **Decision Making:** Capacity to inside take decisions in real time of the control model for levels 0, 1 and 2 of the "automation pyramid" (SEIXAS FILHO, 2000);
- **Strategy:** Definition of a scheduling model based on real time and heuristic rules, accordingly with competitive criteria of cost, quality, delivery speed and due date performances.

Following are presented the problem identification to be approached, the motivation for the problem solution and the aims of the work.

The problem approached

So, the problem is how to obtain NDJSP systems that will have the five desired characteristics previously pointed, through a control architecture of virtual manufacturing cells, that takes care of market necessities, inside of real time scheduling and dispatching dynamics, obeying to "pyramid of automation" division in levels for the layer of control respected to (PEAR - Purdue Enterprise Reference Architecture) and also respected to goals of control for the constituent levels of this layer.

Motivation

The basic characteristics of NDJSP systems, collated to the profiles of the ACT, MTO and ETO consumers demand, results in the necessity to conceive control systems, with capacity to dispatching in real time based on virtual organization (SEIXAS FILHO, 2004).

Considering the integration of job shop manufacturing planning systems and control systems, the difficulties is basically concentrated in the problem to generate a model that effectively represents the desired dynamic behavior to impose to job shop. The biggest joined difficulty is how to obtain it, considering that the planned times and sequences effectively are executed, inside of the



required characteristic of performance. Without a solution of how to execute the process plans as the planned one, that is, inside of its due dates and planned costs, with the defined resources, etc., it will not be obtained to inside take care of the necessities of market of the established profiles of demand, without no type of penalty, either of economic order or that it comes to denigrate of some form the image of capacity of attendance industry order.

Observing the (NAKAMOTO, 2002); (MATSUSAKI, 2004) works, one sees that with the control systems complexity increasing, it has a trend in adopting gradual constraints insertion solution, what it was before a simple model of process sequencing control. This type of procedure results in a model whose difficulty of interpretation and maintenance is increased, beyond its capacity of re-utilization becomes decreased, placing in a delicate situation all the context of control systems design, inside of the dynamic discret event systems (DDES) target. In this context, it is essential to contemplate the necessity of methods and techniques for NDSJP systems modeling, being minimized the insertion of constraints and becoming them more easily to be modified, as well as the adoption of a more adjusted modeling formalisms. The methods and techniques that are considered in this research, aims to guarantee that the final control system model can be conceived from a collaborative control architecture as proposal for (MATSUSAKI, 2004).

Objectives

The approach of this work follows line of other works as (SANTOS FILHO, 2000); (MATSUSAKI, 2004), in the attempt of synthesis and simplification of manufacturing industrial system operation.

Relatively of the approached problem, the aim of this work is the modeling and analysis of NDJSP manufacturing systems, through an approach based on the concept of virtual manufacturing cell, with conceived virtual cells through technique of evolutionary computation, more specifically through a genetic algorithm, and also of one true reactive and real time scheduling and dispatching technique, that guarantees a level of performance established for the system, respected to the use resources capacity and to the use of alternative processes routings flexibility, without any type of penalty caused by reducing use of resources and delays in production orders.

Justification

The justification of this work is based on the world-wide trend of search project methods, current work and production improvements, with emphasis in the subsystems of programming, execution and control. This search is guided and motivated for the potential advantages to use the computers as tools of modeling, analysis and optimization, and not only as database. Beyond the mentioned aspects already, the following aspects in the direction are presented to complete the justification for this work:

- According to Lucero (2001), the small lots job shop type is comparatively to less productive amongst the types of existing productive processes, fact this that can be reverted with methods and more efficient techniques elaboration, for production scheduling and dispatching;
- The strategic needful of flexibility for industries production functionalities, to reach the objectives of product demands;
- The recognized importance for the strategists of the paper exerted by the manufacturing systems programming;
- The lack inside of literature of systemic methods that contain in its structure, the concept that the system must be optimized through the waited final results (SEIXAS FILHO, 2000), opinion shared by this research, and so, not searching the optimization of each system part, separately. Therefore, the necessity of conception of models those take care of the pointed profile.

In this way, the interest for this study is proven; therefore, it will approach the problem of as to make things of structuralized form, looking for using the minimum number of resources as possible, in the transformation of the nature to satisfy the necessities human beings and consuming market.

Processes routings flexibility

Accordingly to Rohde; Boreinstein (2004), the sequence flexibility represents the possibility to alternate the sequence of manufacturing operations of a part, considering the constraints and specifications of its project. Machine Flexibility is related to the possibility of an operation can be executed in a machine of different manners. Routings Flexibility Flexibility mentions the capacity of manufacturing systems to allow, simultaneously, machine and sequence flexibility.

In this work, the flexibility type searched is the processes routings flexibility according of Browne's Taxonomy (BEACH et al., 2000), to deal with the time and sequence indeterminism present in the NDJSP systems.



Many researchers have demonstrated the potential of performance improvement of manufacturing systems under flexibility conditions (ROHDE; BOREINSTEIN, 2004). Considering that flexibility can be an important attribute to the improvement of the systems, the development of models and algorithms capable to represent flexibility are an important step for the design, evaluation and control of these systems.

The concept of “agility” is an emergent concept, and it is used in this research as the capacity of the industry to take care of customers’ demands with the lesser effort as possible, focused in the ready reply to the turbulent and dynamic markets. In this research, an environment is characterized as turbulent when it possess: highly demand and batch size of production changeable; highly times of processing changeable; highly setup times changeable; partial or total random demand; frequent alterations in the mix of products; changeable sequences of production; and hard competition for resources.

Production strategical criteria

Accordingly with Corrêa; Gianesi; Caon (2001), the production strategic criteria are listed as follow:

- Cost: lower possible. In this research the cost is the sum of setup, movement, transformation and waiting for machine costs.
- Quality: best possible performance of quality. It represents the satisfaction to the final customer requirements for the parts.
- Performance of delivery: trustworthiness and speed in the delivery due dates. In this research, this criterion will be guaranteed by the new technique of scheduling and dispatching that will be proposed to follow.
- Reactivity: capacity of fast reaction to the demand for products. The new techniques of clustering and scheduling/dispatching to be proposed in this research will guarantee this capacity of reaction.

The problem in classical static job shop manufacturing systems

The manufacturing problem in job shop systems involves, amongst other things, the resources allocation, for the accomplishment of different tasks throughout a time horizon, with the intention to produce different products.

Definition 1 - Each job is an ordinate set of operations executed in adjusted machines, associated to the manufacturing of a product.

The process of resources allocation offers difficulties in regards to the fact to involve some measures of performance, restrictions and preferences with not clear and conflicting characteristics between itself, where the more common measures of performance to the JSP are: total time of conclusion of all the tasks (makespan), maximum delay, average delay, number of delayed tasks, total delay, amongst the other less common ones. The setting of the measure of performance is preponderant for the solution method choice.

The most common JSP restrictions are the following ones:

- Precedence: the operations of each task have to be executed in the foreseen order;
- Recirculation: when two or more operations of one job must be processed in the same machine;
- Capacity: each machine can only process a task of each time;
- Preemption: each operation, after initiated its processing in a machine, must be concluded without interruption.

Therefore, the classic static JSP is an environment formed by a set of machines that must process a set of jobs, where each job possess a proper sequence of operations, whose processing in the respective machines, demand fixed intervals of time, even so in real situations, nor always these times are fixed. All jobs are available for processing and are submitted to the recirculation and anteriority restrictions, whereas the machines are submitted to the preemption and capacity restrictions. In this research, the capacity and anteriority restrictions are dealt with only. The measure of performance will be based on a priority index, which takes in consideration the times of each stage of jobs processing, the due dates and the delays.

The NDJSP with due date

The production is a continuously executed activity, and therefore, the nature of the programming is dynamic. In one job shop called non-deterministic dynamic, the tasks arrives randomly at the shop floor.

According to Roser; Nakano; Tanaka (2003), the tasks control in one NDJSP is called of reprogramming, because random events frequently need revisions in the programming. In real job shop environments, especially the ones that produce under ordering, the main objective to be satisfied is the tasks due date fulfilment. Of this form, the minimization of performance measure as delay, that has taken in account the instant of tasks conclusion and its respective due dates, possess bigger relevance of what a performance



measure as makespan, for example. Until the moment, the research guided in the direction in such a way to develop solution methods for programming problems, in dynamic job shop, is few, having as main goal to minimize the total tasks delay, and how much to increase its performance (OLIVEIRA, 2002); (VIDAL; BECK, 2003).

Virtual cellular manufacturing

It is proposed a virtual cells formation method that applies one established clustering technique based on genetic algorithm, where the production system part arriving orders allows in accordance with that parts are grouped one to one, considering a time planned horizon. For this, a clustering algorithm was developed, which is responsible for the virtual cells design. The manufacturing virtual cells formation technique is at the same time dynamic and distributed, evidencing to be an excellent way of clustering problem solution to NDJSP systems, and, against the majority of the works found in literature, it inside glimpses the adoption of real alternative processes routings in execution time way, aims to minimizing cells coordination effort and control and cells material manipulation. Moreover, an approach is considered to become cells independent, facilitating the processes and resources cells control.

The classic cellular manufacturing cannot be appropriate if the sequence of operations or the processes routings are will be modified in the time. Some alternatives to the classic cellular manufacturing could certainly answer better to the production, if it is in small lots for NDJSP environments as, for example, the virtual cellular manufacturing systems (MCLEAN; BLOOM; HOOP, 1982).

The concept of virtual cell was firstly introduced by McLean at the beginning of the eighty decade (MCLEAN; BLOOM; HOOP, 1982). In accordance with the definition given for McLean, a virtual manufacturing cell cannot be identified as a physical and fixed grouping of work stations in the shop floor, but as data files and processes in a controller. In other words, a virtual cell is a logical resources and processes grouping into a controller (RATCHEV, 2001).

The Fig.1 illustrates an example of cell shop with virtual cells. Cell shop at the illustrated moment possess two active virtual cells and no resource shared between the cells.



Figure 1 - Example of cell shop with two active virtual cells and no resource shared between the cells.

The organization through virtual manufacturing cells, proposed in this research, presents distributed work stations through the shop floor arranged in resources groupings with similar characteristics, called functional organizations. In such a way, a manufacturing system is designed to give a maximum efficiency all the time and to be capable to support production under ordering, having a minimum possible cost, and it can be gotten, with the adoption of the virtual cells concept.

Important characteristics of clustering techniques for virtual manufacturing cells formation

Accordingly to Hyer; Browns (1999), the virtual cells, in fact, are related as devotion of physical resources to the production of specific sets of good or services, without rearrangement physical, and also are recognized as logical cells. The virtual or logical cells also can be implemented as a precursory evolutionary period of training of future fixed cells. A connection through efficient mechanisms of communication will allow that the virtual cells get many of the advantages typically reserved to the fixed cells.

In the case of NDJSP systems with ACT, MTO and ETO kind of demands, this temporary characteristic is sufficiently strong and, therefore, this type of temporary solution is needful and desired. In these cases, the virtual cellular manufacturing with support in dynamic clustering techniques and scheduling and dispatching dynamic algorithms, become necessary.

New clustering technique

First, it is necessary to make some comments with regard to the adoption of virtual cellular manufacturing concept. To be possible the physical implementation, it is important to break itself of a layout that propitiates the work stations logical and physical



integration of these manufacturing virtual cells. The resources are distributed by the shop floor in units or functional organizations that execute similar activities. The functional organizations proposals in this research compose an area. This layout organization was based on the equipment hierarchy of norm ANSI/ISA S88.01. The Fig.2 shows to the organization proposal for this research.

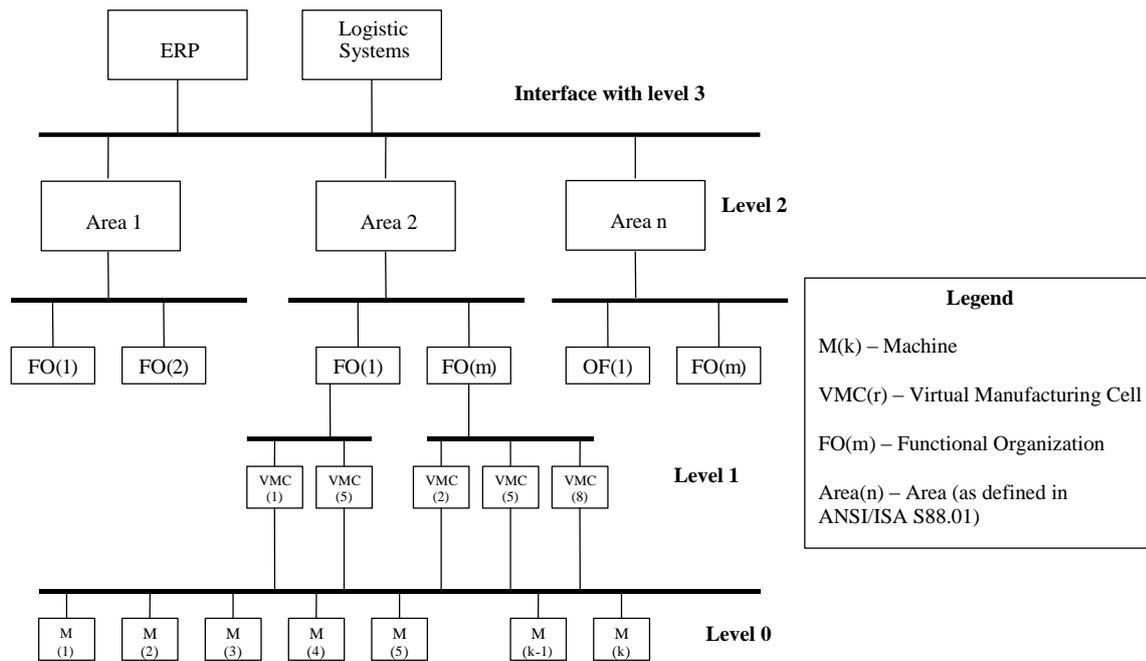


Figure 2 – The proposed physical and logical architecture for the equipment hierarchy.

The proposed virtual cells formation method considered is decomposed in the following steps:

Enumeration of all the existing shop floor resources, as well as the restrictions associated to machines and tasks, survey of the times and the costs associated to these resources for the accomplishment of the activities related to the processes and, finally, survey of the time restrictions;

Machinery functional organization as logical and physical organization proposal to the shop floor resources.

The number of alternative routings determination for each stage (operation) of each process, and also, the number of programming determination for fulfillment of the alternative routings for the stages of each process. The number of routings for each part stage will be calculated on the basis of the stages number for the each part manufacturing. The maximum number of routes for stage will be gotten by eq. (1).

$$Routes_i = \left\lceil \frac{Stages}{2} \right\rceil \tag{1}$$

where: $\lceil \cdot \rceil$ means the minor integer bigger then, i is the index of the part and Stages corresponds to the sum of activities for part i . Whenever the maximum number of Routes will be equal the 1 (one), it will be adopted, for convention, that this number is equal the 2 (two), to guarantee the minimum flexibility of routes for each part stage. This restriction serves to prevent the combination explosion of alternative routes and to guarantee a small and feasible number of programming (economic solution) by stage for each part. Eq. (2) it establishes the product of logically possible routes without no restriction. Already the number of programs is gotten by eq. (3).



$$\prod_{i=1}^{stages} r_n \quad n = 1 \dots \text{routes for a part} \quad (2)$$

$$\sum_{i=1}^{stages} r_n \quad n = 1 \dots \text{routes for a part} \quad (3)$$

Where: i corresponds to the stages index and n is the processes (parts) index.

Determination of the interval for the possible amount of being used machines is given by:

$$\text{Min \{Part Qty, Stages Qty, Machine Type Qty\} } \leq \text{Number of Machines} \leq \text{Max \{Part Qty, Stages Qty, Machine Type Qty\}} \quad (4)$$

The machines ideal number is frequently impracticable, because the high amount of machines to be placed in availability for the virtual cells. The minimum number of machines becomes impracticable; therefore it does not allow that alternative plain are conceived, using the criterion of machine duplication. It is important to remember that the cells that are being projected are independent. Of this form, all the resources necessary to all the plans of all the parts to be manufactured inside of the virtual cell must be part of it. In this way, a new interval must be used.

$$\text{Machines}_{\text{Min}} \leq \text{Number of Machines} \leq \text{Machines}_{\text{Stages}} \quad (5)$$

Determination of virtual manufacturing cells for a planning horizon (PH). This stage represents the determination of the cells quantity for the PH, the amount of machines (group of machines) and the determination of the types of machines to compose the virtual manufacturing cells, as well as the families of parts to be processed inside of each virtual cell. From the process with bigger number of stages, is transferred to establish it the best distribution of frequencies of process routes. For this, it is necessary to raise the cells number for the PH. The cells number will be limited by the biggest frequency of routes for the PH. In this way, the virtual frame number to be formed for the PH is given by:

$$F \leq \left\lceil \frac{\text{Frequencies_Sum}}{\max(\text{Route_Frequency})} \right\rceil \quad (6)$$

$$F \geq \left\lfloor \frac{\text{Frequencies_Sum}}{\max(\text{Route_Frequency})} \right\rfloor \quad (7)$$

where, *F* is the cells number for the PH, $\lfloor y \rfloor$ means the lesser integer greater than *y*, $\lceil y \rceil$ means the minor entire bigger than *y*, *Frequency Sum* is the frequency of use for the machines considering the sum of all the individual frequencies related to the parts to be processed and its alternative routings, and *Route Frequency* is the frequency for the alternative routings considering them individually;

Application of a genetic algorithm to define which the machines, and process routings will be part of the virtual manufacturing cells;

Generation of the necessary global scheduling (referring to the PH for the virtual manufacturing cells) and to the local scheduling (for the tasks inside of each cell) information, according to routing, machines and staff flexibility foreseen for the previous selected alternatives.

Scheduling and dispatching dynamic technique for NDJSP

The scheduling and dispatching algorithm proposed is based on a combined heuristic rule (CHR). In the eq. (9), is showed the problem treated in this work.



$$(Jm / prec; recrc; P_{ij}; C_{ij}; t; d_i; S_{ijk}; M_i \subset P / \text{Combined Heuristic Rule}) \tag{9}$$

The formal notation used can be obtained in Brucker (1998). To better characterizing the scheduling problem and the CHR rule adopted in this work, some important characteristics will be placed now:

- Jobs and tasks continuous arrival: the orders arrive continuously, of this form the chosen scheduling are dynamic;
- Not activities preemption: when an activity is processed, the other activities cannot interrupt it;
- Routes availability: alternative process routings can be used;
- Estimated processing time: the processing time of each activity for any job is estimated (not real because the indeterminism of time completion). This time measure is obtained by timing and statistical classical methods, and the alternative machines can require different processing times for the same operation;
- The setup times are small if related with the processing times. In such a way, it is assumed that the system have got fast tool exchange;
- The system does not suffer deadlock: the execution of the system possess a dynamics that makes it difficult the blockade, therefore the algorithm works with small time windows for the comment of the future behavior being based on a list of priorities, and still, it can be chosen amongst the alternative process routings;
- The total absence of intercellular movement;
- Unexpected events, as machine breakdown and raw material lack at the execution moment, must be taken in consideration in real world production systems.

The proposed CHR combines the characteristics of SPT and S/RPT heuristic rules (VIDAL; BECK, 2003). It contributed for this choice an important factor, where the rules to be agreed had been the ones that have got aims more adequate to the scheduling problem to be decided. To compose the agreed heuristic rule for this work scheduling problem, SPT and S/RPT rules are presented as good candidates, for the fact to prioritize the increase of the production flow and the due dates fulfilment, respectively. Using SPT, as a heuristic for the priority index determination, can be reduced the time of the production flow, and consequently, be reduced the costs of production system inventory. On the other hand, S/RPT is due date driven, necessary in systems whose demand for products is guided upon orders.

The difficulty to combine these two rules in an only rule is real, because the nature of rules priority orders, respectively. S/RPT rule possess an order of increasing priorities. It means that the order, with lesser value of priority index, corresponds to the major priority activity. Already SPT rule possess an order of decreasing priorities. To decide this conflict, an inversion of signal in rule S/RPT will be introduced.

Eq. (10) represents the priority index (δ) for the CHR and corresponds to the two rules product, plus a adjustment of signal for the establishment of a decreasing order of priority.

$$\delta = \frac{1}{\sum_{q=j}^{mi} p_{iq}} \left[1 - \frac{d_i - t - \sum_{q=j}^{mi} p_{iq}}{\sum_{q=j}^{mi} p_{iq}} \right] \cdot \left[\frac{1}{q_i} \right] \tag{10}$$

The p_{iq} is always the biggest processing time for the stages individually, considering the possibilities generated for the alternative routings. In this case, the worse remaining path is always analyzed. Finally, an amount factor ($1/q_i$) can be used to give preferential treatment to jobs with the lesser number of items being processed, when it will have ties up to more in relation to the combined index for two or more jobs.

Following the order of priority established by RHC, the scheduling algorithm will have to take care of the activities that compose jobs having as criterion the instantaneous values of priority for jobs tasks candidates to the resources allocation.

Branch & Bound algorithm for on line scheduling and dispatching

The virtual manufacturing cells scheduling and dispatching algorithm is described below.



Beginning: it initiates the plan horizon PH(i), initiates Cellsi(j) - it reserves machines (resulted of the clustering technique) for the PH(i) virtual cells, that is, could not be used for other processes if it are out of the PH(i) virtual cells;

While there is an active cell in the PH(i), repeat:

Step 1: Generates a list of free resources to be used – fr (iteration);

Step 2: Generates a list of waiting for resources stages in accordance with the jobs precedence graphs - Sw (iteration);

Step 3: Priority coefficient (δ) calculation only for waiting for resources stages;

Step 4: Generates a list of waiting for resources stages priorities in accordance with the increasing (δ) values;

Step 5: Allocation of resources (machinery) to the waiting for resources stages in the top of the priority list, and also, in accordance with the machines availability. The resources to be chosen for the stage must be those that permit the lesser cost and waiting time to the stage;

Step 6: Priorities list actualization (without the previous stage designated in Step 5);

Step 7: Iff Cellsi(j) is finished, the cell's machines must be liberated to be used by other virtual cells, or else go directly to the Step8;

Step 8: Iff PH(i) is not finished, then go back to the Step 2, or else go to the Step 9;

Step 9: End of PH(i) – Liberates all machines to other schedulings;

End Repeat.

Results analysis method

Firstly, it is needed to remember that the proposed algorithm is based on a CHR and, that therefore, the validation in this case is differentiated. The approaching that will be given is expressed the creation of a simulation model that has taken in account the algorithm of scheduling and dispatching proposed for assignment of the resources in real time. It is starting, at this moment, to describe the results of the simulation and analysis method gotten by simulation:

- Creation of a random artificial scene of PH for analysis.
- The characteristics establishment of timming randomly and indeterminism provoked by breakings down and machine stops.
- New scenes repetition and performance analysis of each one of the scenes being based on the PH total delay and to the cells individually as performance measuring.
- Percentile analysis of the unsatisfactory performances in relation to the satisfactory ones.
- Graphical analysis of these performances.
- And finally, to present the final results and conclusions.

The new techniques examples of application and results analysis

Some NDJSP systems analyses had been lead through simulation software called DEVICE (Design of Virtual Cells), which it makes possible the genetic algorithm application to the processes of a virtual cell and the processes performance analysis for production scenes artificially produced, through the news techniques of clustering and scheduling/dispatching. This program still makes possible the evaluation of some produced scenes parameters, being able the information to be stored and to be visualized in literal and/or graphical format, beyond archives of data.

An application example of the used genetic algorithm in the new clustering technique

For the clustering technique genetic algorithm (GA) analysis, was extracted of literature (CHAN, 2003) an example considered adjusted to this work type of system approached, that is, NDJSP manufacturing systems with alternative process routings. In the original problem of Chan (2003), the author describes the unitary processing times. However, analyses for diverse demands for products are made. The values of demand for chosen products are shown in Table 1.

Table 1 – Product demands.

Process	Demand
1	7
2	7
3	5
4	5



5	5
6	7
7	7
8	7

Chan (2003) used some dispatching rules aiming to verify the effect of these rules together with the use of alternative process routings in the performance measuring of a flexible manufacturing system and found a measure of performance (makespan) next to 1000 minutes for the chosen demand. For small demands, the author concluded that the dispatching rules have very next performance.

It is considered these processes as integrant processes of a virtual cell. It was initiated, then, for the application of the GA for the best set of processes routings choice and for the machines definition that will compose the cell, together with the identified processes already. The question now is to determine which resources to place for this cell. In other words, as to choose the best routes, that use the lesser possible number of resources (machines), with the best one performance measured (better makespan) and the lesser cost?

The introduced modifications nothing had more been that the increase of the alternative process routings, introducing new possibilities of routes, with intention to provoke bigger variations in the population of individuals (possible solutions). Table 2 brings these modifications. The P_{ij} term mentions the task processing time i in machine j and the C_{ij} term is mentioned at the processing cost, respectively.

Table 2 – Processes description for the modified problem

Item	Process	Operation	Machine	P_{ij}	C_{ij}
1	1	1	1	105	1
2	1	1	2	126	1
3	1	1	6	91	1
4	1	2	3	168	1
5	1	2	4	140	1
6	1	3	5	70	1
7	1	3	3	140	1
8	1	4	2	210	1
9	1	4	1	175	1
10	1	4	4	175	1
11	2	1	2	140	1
12	2	1	3	168	1
13	2	1	7	154	1
14	2	2	3	70	1
15	2	2	2	112	1
16	2	3	5	245	1
17	2	3	2	266	1
18	2	4	4	175	1
19	2	4	5	203	1
20	3	1	5	200	1
21	3	1	1	100	1
22	3	2	1	125	1
23	3	2	2	60	1
24	3	2	7	60	1
25	3	3	4	150	1
26	3	3	3	135	1
27	3	4	2	75	1
28	3	4	4	90	1
29	4	1	4	150	1
30	4	1	2	75	1
31	4	2	2	150	1
32	4	2	5	75	1
33	4	3	5	100	1
34	4	3	4	50	1
35	4	3	6	100	1
36	4	4	3	125	1
37	4	4	1	75	1

Item	Process	Operation	Machine	P_{ij}	C_{ij}
38	5	1	1	50	38
39	5	1	3	40	39
40	5	2	3	100	40
41	5	2	4	150	41
42	5	3	2	75	42
43	5	3	5	100	43
44	5	3	6	125	44
45	5	4	4	150	45
46	5	4	3	125	46
47	6	1	3	175	47
48	6	1	5	140	48
49	6	2	2	84	49
50	6	2	4	56	50
51	6	2	5	70	51
52	6	3	1	175	52
53	6	3	4	140	53
54	6	4	5	70	54
55	6	4	3	161	55
56	7	1	4	245	56
57	7	1	1	266	57
58	7	1	3	245	58
59	7	2	5	70	59
60	7	2	4	126	60
61	7	3	1	70	61
62	7	3	4	105	62
63	7	3	7	105	63
64	7	4	2	105	64
65	7	4	5	70	65
66	8	1	5	105	66
67	8	1	4	70	67
68	8	2	4	280	68
69	8	2	5	210	69
70	8	3	3	175	70
71	8	3	2	140	71
72	8	4	1	140	72
73	8	4	2	56	73

GA application results to the original problem

One of the most laborious tasks in the GA applications mentions the parameters tuning of the GA algorithm. The [http:// www.gjesrm.com](http://www.gjesrm.com) (C) Global Journal of Engineering Science and Research Management



developed program, allows that these parameters are modified as desired, however, the proper program tries to make an automatic tuning of some of these parameters. This automatic tuning is mere empirical and was based on the empirical observations of this work author about GA applications.

It was observed that the original problem have got excellent distribution of the tasks amongst the machines and that the process plans had led to the generation of well homogeneous populations, with a certain elitism's degree. In the attempt to illustrate a little better the GA, had been lead modifications in the process plans to confer more heterogeneous characteristic to the populations of individuals (solutions). With a more heterogeneous space of solutions, it was possible to more clearly perceive the mechanism of solutions search used for the GA.

GA's application results to the original problem

The simulation results had been gotten for a population analyzed of 72 individuals, 64 generations, 8 mutations, crossover percentage of 70% and a mutation percentage of 2%.

In Fig.3 the graphical representation of the GA evolution for the modified problem is shown, gotten through DEVICE program.

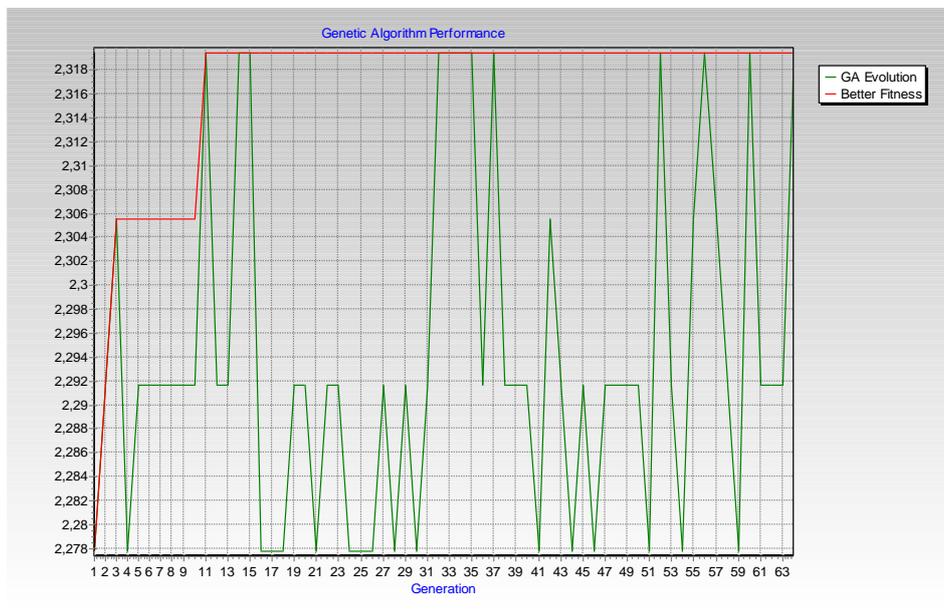


Figure 3 - GA graph evolution for the modified problem of Chan (2003).

The result showed that the population of individuals (solutions) represented by the modified routes is more heterogeneous of what the original problem population. This must to the process routings flexibility increase. Moreover, the new introduced machines, machines m6 and m7, had been with a measure of frequency so much below related to the other machines, and it is a great problem in the cells work load balancing.

In an analysis more detailed of the production scenes simulations, made possible by DEVICE program, considering the routes that use these machines and the case of the original problem that will not count these routes, it was verified that the measure of modified problem makespan was below of the original problem makespan measure, as expected. This proves that the increase of the process routings flexibility, together with the best routes choice that lead to the best solution considering as measure of performance, the makespan, is true. However, it must be analyzed through economic criteria, until where is beneficial to use more resources (machines) to produce, since these resources improve the measure of system performance, but on the other hand, the resources can little be used throughout a PH, and with this, be little economic.

The used GA allows, amongst other things, the detailed analysis of the operational flexibility impact introduced by the effective use of alternative routes, in the final virtual manufacturing cells design.



To prove all the initial hypotheses, it was become the analysis of two application examples of the scheduling and dispatching technique in real time. These examples are shown in the next topic.

Examples of proposed scheduling and dispatching technique using in real time

First, they had been chosen in technique literature, two examples of JSP with alternative process routings. To confer to them characteristic of NDJSP problems, program DEVICE allows that the times of processing for the job operations can be modified in time of execution, as they were unexpected events, in random way, and in the ratio desired for the designer. Program DEVICE allows despite the accompaniment of the processes, for each scene of production bred artificially, can be made through the graphical visualization in the computer screen. The production scenes information is showed through Gantt graphs for the machines or processes and of a graph that totalizes the measures of performance (makespan) occurred for each set of scenes. The program allows despite the penalties associates to the used scheduling/dispatching rule in this work, can be visualized in the graph. Another penalty that can be visualized mentions the not reach of due date. All the information can be stored in graphical electronic files format.

New technique scheduling and dispatching application result to the problem considered in Table 2.

As the problem of scheduling treated in this work, mentions the original problem to it considered by Chan (2003), the performance measure (makespan) for the optimal solution found by Chan (2003), considering the same demand adopted for this research, was of 1000 minutes.

In the Fig.4 the result of the simulation's performance measure (makespan) of 50 different scenes is presented, for 0% of variation in the processing times.

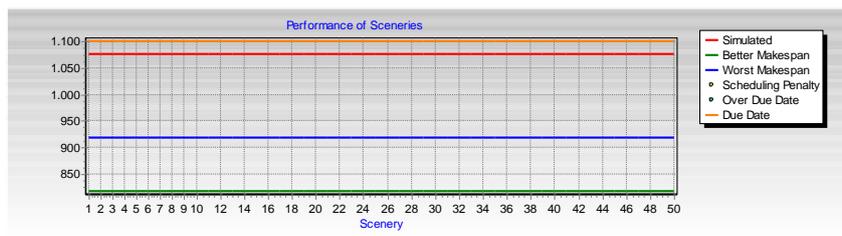


Figure 4 – System performance for 50 scenes with 0 % of processing time variation.

It was observed that for the 50 scenes simulation with 0% of processing times variation, that is, an equal problem solved for Chan (2003), the joined solution was not so far, but makespan was greater that the found one for the author. However, the solution proposal for Chan (2003) does not foresee turbulence as in this work.

In the Fig.5 and Fig.6 the Gantt processes and machines graphs are presented, respectively

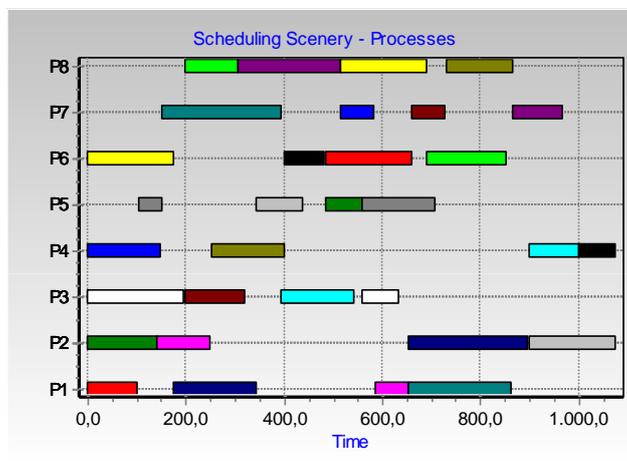




Figure 5 – Processes Gantt graph of the first scene with variation of 0% in the processing time.

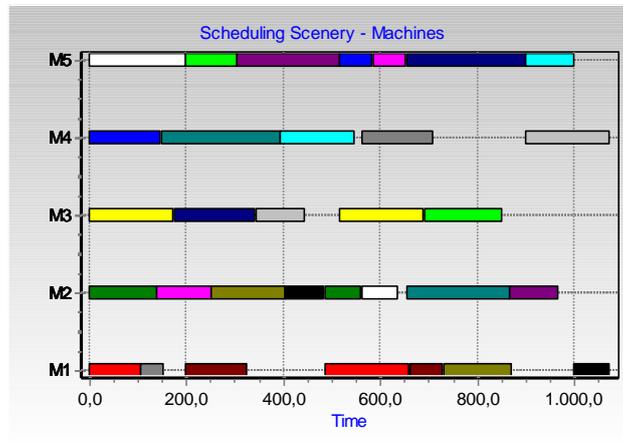


Figure 6 – Machines Gantt graph of the first scene with variation of 0% in the processing time.

The performance analyses of the new scheduling and dispatching technique for turbulent environments are initiated here. Fifty different scenes for variation times of 5, 6, 7 and 10% had been simulated, respectively. In the Fig.7 the result of the performance measure (makespan) for the 50 different scenes simulated is presented, for the variation of 10% in the processing times. The simulation considered a due date for the processes of 1100 minutes and an equal demand to the demand specified in Table 1.

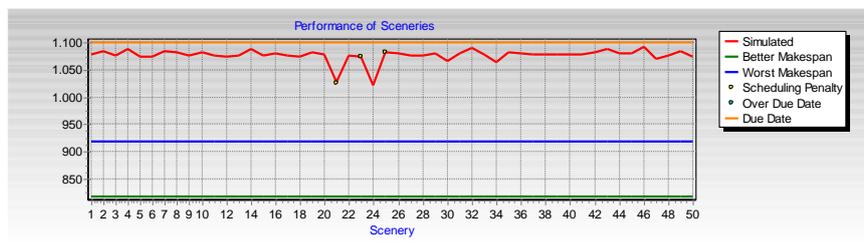


Figure 7 – System performance measured for 50 scenes with processing time variation of 10%.

Analysis of the penalties applied to the schedules for the scheduling algorithm

To illustrate the penalties, and analyzes its effect in the construction of schedules and in the system performance measure, and to show the easiness to it to remake the schedules of the penalties processes, the number 23 scene of the Fig.8 was used. In the Fig.8, the graph of tasks allocation for the processes of the problem considered for Chan (2003) and simulated in program DEVICE for 50 scenes with variation of 10% in the time of processing, referring is represented to the twenty third simulated scene.

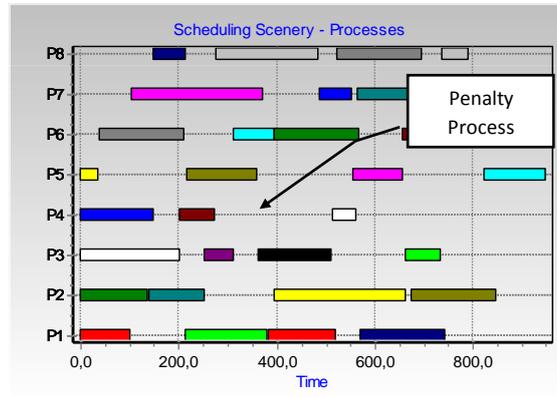


Figure 8 – Processes Gantt graph of de twenty third scene with variation 10% in the processing time.

The twenty third scene generated by the scheduling and dispatching algorithm presented a penalty related to the impossibility of generation of all the schedule for the process of number 4. The last stage of the related process was not scheduled by DEVICE program. Does not mean that this stage cannot be scheduled. The execution of the last task of the last process can take place after the last task executed by the scheduling and dispatching algorithm.

This penalty generated by DEVICE program is inherent to the scheduling and dispatching algorithm proposed in this work and serves to visualize the power of generation of reactive schedules, that is, without the interference human being. The algorithm observes only the information generated for the system in execution time. However, when the environment becomes very turbulent, with intense variations of processing times, penalties can occur. In these cases one becomes necessary that a human operator programs one or more stages for the penalties processes.

In the specific case of number 4 process, the last stage could be carried through in the machines of number 3 or 1 with the times of processing in minutes of 125 and 75, respectively. The complementation of the missing schedules must after be made the ending of the last scheduled stage for the system. This makes with the performance measure is worse, that is, makespan becomes bigger. However, for all the scenes simulated in the two examples of this work, are always possible to remake the scales in case of penalties.

These penalties are related to the production bottlenecks and the use of an algorithm based on a queue with the respective priority indexes for the end tasks accomplishment. This reflects the lack of legal capacity of the used heuristic to deal with production bottlenecks in environments with many hard disturbances related to the tasks processing times. However for small disturbances, the scheduling algorithm revealed efficient.

It was observed that the new real time scheduling/dispatching technique obtains to work with unexpected events and time and sequence indeterminism, with little or no damage in relation to the performance measure and no damage with regard to the due dates and speed of delivery. However, how much bigger the variations in the processing times, more penalties related to the used heuristic for the scheduling algorithm, happen. It was verified necessity to incorporate the CHR, a heuristic that has led in consideration, possible production bottlenecks.

A first evaluation, one gives credit that techniques of deadlock avoidance, applied the productive systems (NAKAMOTO, 2002), can be a way to define established heuristic rules in these techniques to solve problems of bottleneck production, as for the possibility to identify the production bottlenecks in front of, improving the gradual characteristic of the CHR. It was evaluated despite the gradual characteristic of the new scheduling and dispatching technique not yet is totaling satisfactory. However, with so much simple rearrangements for the last tasks of each scene that had suffered penalties, it is possible to reconstruct the schedule easily.

Final conclusions and future works

The NDJSP manufacturing systems programming method considered in this work explores positive points of the virtual manufacturing cells, the evolutionary computation and the heuristic methods of scheduling and dispatching of manufacturing systems.

The scheduling technique of this work revealed independent, steady, adaptive, flexible, contingent, monotonic and relatively robust. The robustness was compromised by the incapacity of the heuristic rule combined to deal with bottlenecks generated for hard turbulences provoked in NDJSP system. However, this did not compromise the good course of the processes. The only compromising occurred became related only with the performance measure (makespan).



As said, the programming method revealed adequate to the initial objective, however the CHR have got restrictions in dealing with production bottlenecks in such a way. It is necessary to improve the progressive characteristic to the scheduling and dispatching technique (VIDAL; BECK, 2003).

The genetic algorithm revealed adequate for the choice of the best set of routes, therefore it made possible to find feasible and balanced solutions, in a fast form and with low computational effort, for problems of NP-complete type like dispatching in NDJSP.

This work contributes in the following aspects related to the NDJSP tasks programming:

Definition and creation of a balanced virtual manufacturing cells technique in relation to the objective of formation of smallest cells and with length of tasks frequencies measures very next, for deterministic slices of time called of PH.

Definition and effective use of alternative processes routings inside of the virtual cells formed and not choice of simple routes to the end of the cells formation activity, making possible the creation of reactive schedules trully.

Definition of a schedule generation technique for the execution of process manufacturing operations, in execution time, with high frequency of use for the resources and performance measure (makespan) next to the optimal value, exactly that in turbulent environments.

Definition of a NDJSP tasks programming method, based on defined virtual manufacturing cells from deterministic functional organizations and time horizons. This method is precursory of a control collaborative architecture that it intends to define in a next future. The nucleus of the scheduling and dispatching activity is represented by a hierarchy divided in two levels, control of the cells and control of the processes inside of each cell. This activity of scheduling represents a functionality of the control processes semantic level of the architecture proposal for (MATSUSAKI, 2004).

The found solution to decide the problem of this work, with respect to the way of how to get a solution for the scheduling and dispatching problem, bringing for the control layer this activity. This solution also favors the specification of a control collaborative architecture for NDJSP systems. For this, one becomes necessary to specify other inherent activities to the control, not foreseen in this work, that not only the activities of scheduling and dispatching. Moreover, one becomes necessary to work with different control architecture of the traditional hierarchic control architectures, as top-down. The way that if considers mentions the type of solution proposal for (MATSUSAKI, 2004). Matsusaki (2004) considers a solution where diverse the semantic ones are separate in distinct controllers who interact, between them, to reach the individual and the global control objectives of the production system.

Still in this proposal of control model, problems as deadlock avoidance, problems of transport, assignment, etc., with different semantic, must be solved, adding it the solution found in this work. The solution found deals with the macro level of part of the NDJSP control problem, which is, as to inside generate reactive schedules to the control layer, making possible with this the implementation of the scheduling and dispatching activities in controllers of process, that is, in execution time.

The adoption of a collaborative control model divided in the semantic levels of processes control and resources control, is much more adjusted of what hierarchic architectures of the top-down type, why according to Matsusaki (2004), this type of architecture allows the treatment of the global process complexity of these systems in much more adjusted way.

Future works

In reply to the gotten results, it is presented as future works proposal the following items:

To improve the CHR, to confer the progressive characteristic to the scheduling and dispatching technique, beyond the objectives to increase the processing flow and to take care of to the due dates without penalties for delay and of a new objective to prevent penalties due the production bottlenecks.

To investigate the deadlock avoidance solution mechanisms to consider a procedure of bottlenecks identification in NDJSP systems, based on the procedures of additional control rules generation, the techniques of deadlock avoidance and to translate the procedure of bottlenecks identification in one heuristic to be combined to the CHR proposal in this work.

To establish the NDJSP control model through the approach proposed in this work. This model will be based on the modeling proposal of (MATSUSAKI, 2004), that is, a model of collaborative control, since the solution gotten in this work represents only one small part of the control model, still in the macro level, but that it was necessary to be decided, for then only being able to consider the complete NDJSP control model.



To really apply this model of control.

To extend DEVICE program to be able to simulate diverse cells at the same time, as well as entrance of processes information in the graphical format through precedence graphs and tables associates to these graphs and, also, to be able to compare results to the application of more than one heuristical rule at the same the problem and at the same time, conditions these necessary ones to analyze the control model that intends to develop.

It is observed that this work is a proposal of as a highly dynamic environment as the NDJSP manufacturing systems can be programmed, guaranteeing the desired performance characteristics to them, the spite of the inherent complexity to the programming of this type of environment, reaching the business-oriented objectives inside of the profiles of demand guided the orders.

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