Optimization of production in workshops with reconfigurable machine tools

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Abstract

The development of production systems, coupled with the growing demands of the market, brings the need for changes in the industry. The transition from flexible manufacturing systems to reconfigurable manufacturing systems (RMS) today gives companies a high adaptability. The existence of reconfigurable machine tools (RMT) that simplify processes and in turn lower the producing costs set or product family is the main feature of these systems. There are many studies on RMS today. This has led to a large number of investigations related to the RMT manufacture and its characteristics. On the other hand, a neglected element in relation to this type of machines is the research lack that addresses the optimization of the production in workshops that possess these RMT. The present research work has the characterizing task of the evolution of the RMT study, deepening in the subjects related to the production planning as element for the process optimization. In turn, an analysis of the Job Shop Scheduling Problem (JSSP) and the existence of modeling cases of the RMT with this problems type.

Keywords: Reconfigurable machine tools, Job Shop Scheduling Problem

1. Introduction

At present the planning problems or the tasks programming exhibit a very broad field of application and can be presented in both service and productive facilities. An example of this is the treatment given to waiting lists to treat patients in hospitals, to distribute the activities that are assigned to students and teachers in schools or the dispatch order of aircraft at an airport. On the other hand, we can mention the technological sequences of operations assigned to a production line or the order of repair and/or device maintenance within the repair sequence, the definition of transportation routes, etc.

The scheduling problems are considered by the specialized literature as an extremely difficult task which requires an important calculation need. At the same time, the great practical relevance makes it an active area of research since its incorporation into the operating business systems exponentially increases its complexity, giving birth to a set of restrictions that limit the real system interpretation and that may be key for the optimization of it.

Several models have been used, using different approaches and with varying success degrees, proposed by different researchers when dealing with this type of problem. Among the most cited can be mentioned: within the field of mathematical programming (Mathematical Programming) Johnson (1954) and mixed whole linear programming Manne (1960); VanHulle (1991); Giffler & Thompson (1960); French (1982). And pruning techniques Branch (Branch and Bound) Conway et al, (1967).; Lagewegm et al. (1977). Simulated Recognition Techniques (Simulated Annealing) Perregaard (1995), Neural Networks (Neural Networks) Zhang & Huang (1995), Genetic Algorithms (Genetics Algorithms) Zalzala & Flemming (1997), Colonies of Ants (Ant Colony) Dorigo & Stützle (2004) and techniques based on Bottlenecks (Shifting Bottleneck) Adams et al., (1988); Schutten (1998).

1.1 Materials and methods

The use of theoretical methods such as analysis - synthesis allowed processing the empirical and theoretical information on the problem characterization, the object and the action field, as well as the partial and general investigation conclusions. The historical- logical continuation made it possible to study the research background related to optimization techniques and scheduling problems, in the specific historical conditions through which this topic has gone through. Likewise, based on the Systemic-structural method, the scientific logical structure of the research and the modeling of the problem object of study are achieved. Modeling was used to analyze and synthesize the real system behavior to a mathematical model, as well as to interpret mathematical models studied.

In addition to this, empirical methods were used, such as the documentation study for the bibliographic documents review that provide information on scheduling problems, the optimization techniques development and the most widely used optimization models.

1.2 Analysis of the results

The constant computational technologies development and the appearance of new heuristic simulation and optimization techniques that take full advantage of the intensive calculation availability have opened a new way to address sequencing problems or scheduling problems. All this development has led to the creation of a methods

arsenal and algorithms whose use allows the old rules replacement and algorithms traditionally used. (Blazewicz, Ecker, Pesch, Schmidt, & Weglarz, 2007) (Carlier & Pinson, 1989) (Pinedo, 2008)

In Cuba, since the early years of the 21st century, a researchers group began to address this type of problem, obtaining relevant results in this science area. One of the pioneers in this type of research is the CAD / CAM Study Center belonging to the University of Holguin (UHo). As a result of its investigations may be mentioned: "Sequencing production lines" (Del Risco Alfonso, 2002), this paper evaluates the general method for sequencing n jobs and m proposed by Johnson (1954) machines and provides a new approach to solution of this case. On the other hand, the research "*Neural Network Modeling and Simulation of the Scheduling*" (Ávila Rondón, Infante Hernández, & Carvalho, 2007) uses the application of Artificial Neural Networks as a tool to solve this type of problems.

The work entitled "Optimization of programming (scheduling) in machining workshops" (Márquez Delgado, 2012), is one of the most recent research which proposes a model that gives solution to three variants of the *Job Scheduling Problem (JSSP): jobshop , flowshop and permutational-flowshop*. At the same time, it enabled the optimization of eight objectives: maximum road, total flow, machine leisure, advancement and delay work, punctual number and unpunctual work and energy consumption of the machines.

Based on Dr.C. José Eduado Marquéz Delgado work's, the research was developed "Optimization of the programming in machining workshops with parallel machine tools and parts recirculation" (Herrera Márquez, 2015). In this it proposes a modification in the model taken as a reference, in such a way that it contemplates the machines work in parallel and the pieces recirculation, thus eliminating both existing restrictions in the previous investigation.

Parallel to these works, others were developed in several institutions in the country, among which we can mention: "Solution to the sequencing problem in parallel machines using Reinforced Learning (*Q- Learning*)" (Suárez Ferreira, 2010) and "*A Generic Multi-Agent Reinforcement Learning Approach for Scheduling Problems*" (Martínez Jiménez, 2012) both at the Central University" Marta Abreu "de las Villas. In addition, studies related to metaheuristic calibration have been carried out, highlighting the work carried out at the "Ignacio Agramonte" University of Camagüey "Behavior of the Main Parameters of a Simple Genetic Algorithm for Planning Problems in Machining Technological Processes with FlowShop Environment" (Fonseca Reyna, 2012). This is a study of the different parameters of a simple genetic algorithm with the improving aim the convergence of this method in this type of problems solution.

The development and manufacturing systems evolution brings changes to the tools and machine tools that are used in them. The leap from dedicated manufacturing systems (DMS) to flexible manufacturing systems (FMS) was a great engineering achievement. Even so, both systems have limitations and advantages among themselves, being necessary sometimes to maintain the use of one or the other depending on the production type to be executed. Table 1

Manufacturing Systems	DMS	FMS
Limitations	Low flexibility	High costs
	Fixed capacity	Production of short series
Advantage	Low cost	Flexibility
	Operation with multiple tools	Scalability

Table 1 Comparison between DMS and FMS.

The disproportion between the cost and the production volumes to be elaborated in these systems helped to promote the third system emergence: Reconfigurable manufacturing system (*RMS*).

These systems are composed for machines set that have specific characteristics. These characteristics allow these machines to be able to adapt quickly to the production demands. The great flexibility that they present, and the competitive cost makes them attractive to the market, which favors a high growth of this technologies type and also captures the engineering researcher's efforts.

Depending on the acquisition costs and manufacturing, the DMS are the most accessible systems but their functional rigidity constitutes a limitation for the modern company. On the other hand, the high cost of installing the FMS is a problem in relation to the production volumes to be assumed by them. Hence, the RMS is able to combine both

systems advantages allowing high flexibility and high production volumes at a competitive cost for the industry, conditions that make them attractive to the industrial sector. Figure 1



Figure 1 Flexibility vs. production volume of machine tool types

If we make an analysis of its characteristics in two (integrability and personalization) of them reference is made to the *set-up time* and *ramp- up time*. These times indicate the machine ability to respond to reconfigure and assume a new type of production, usually the same family products, although sometimes it may be the case that it is able to produce products from a different family, through the change and complete modules assembly.

If these reconfigurations happened arbitrarily in the industry, the productive processes efficiency would be very low, influenced by the high expenses of time spent in adjusting the machines, hence the need for studies that determine the amount of adjustments needed, depending of the size of the production lot and that in turn enables the integration of these systems in productive chains where other types of machines are available.

The operations programming has associated different subfunctions, three of the most significant for the development of the present investigation are loading, sequencing and timing. In general, typical sequencing problems are often referred to as "*Job Shop Scheduling Problems*" (*JSSP*). This problem set is characterized by the presence of two significant elements:

- **Route**: sequence established a priori, is the arrangement in which each works passes through the different machines.
- Sequence: unknown problem is the order in which each machines receives the work.

Numerous are the authors who treated and treat about the *JSSP*. Although it is difficult to define the subject beginnings, the book "Industrial Scheduling" published in 1964 by Muth and Thompson is the starting point for the investigations that followed.

B. Roy and B. Sussman in 1964 were the first to propose representation through the disjunctive graph and Egon Balas in 1969 was the first to apply an enumerative approach based on this graph. However, there are previous works: B. Giffler and GL Thompson proposed in 1960 a priority dispatch rules algorithm; JR Jackson in 1956 generalized SM Johnson's flow shop algorithm from 1954 to the job shop algorithm and in 1955, SB Akers and J. Friedman applied a Boolean algebra model to represent processing sequences. (Herrera Márquez, 2015)

Depending on the use of the machines and the route followed by the work within the workshop there are several flows classifications.

- Random Flow (*Open Shop Scheduling, OSS*): There is no restriction regarding the use order of the machines by the operations of each job.
- General flow (*Job Shop Scheduling, JSS*): Productive configuration where each job is processed in machines set in a certain order. A number of *n* jobs must be processed only once per *m* machines, with an order and for a given time.
- Flow regular (*Flow Shop Scheduling, FSS*): All jobs use the machines in the same order. No piece visits the same machine more than once. It is a particular case of the Job shop.
- *Permutational* flow (*Permutational Flow Shop Scheduling, PFSS*): It is a particular case of the regular flow in which, in addition, the works sequence is the same in all the machines.

- Generalized regular flow (Generalized Flow Shop, GFSS) is a particular case of the FSS, where some jobs do not visit all the machines; however, the unidirectional flow of the work is maintained. This means that some jobs could skip work stations, or what is the same to present processing times equal to zero in some machines, without this creating a counterflow in the movement sense of the work by the workshop.
- Flexible regular flow (*Flexible Flow Shop Scheduling, FFSS*) is a special case of the variant *FSS* and introduces the existence of machines in parallel. Instead of *m* machines in series, there are *s* stages in series, so the jobs move between stages describing a first-in-first-out behavior (*FIFO*) by its acronym in English. Each stage includes a machines number which can be used to process certain operation, however, in a step *S*_i aj work only requires one of the available machines.
- *Flexible Job Scheduling* Flow (*FJSS*) is a special case of the JSS variant, as in the previous variant, there are several machines that can process a certain operation (machines in parallel), grouped together in stages. The trajectory of each job through the stages does not have to be the same. At each stage the machines can be identical, similar or uniform, or different or unrelated. This *Scheduling* problem variant, due to its characteristics, constitutes one of the most comprehensive, since it also offers the possibility of analyzing situations that originate in real production systems.

Authors such as Conway, Maxwell and Miller (Conway, Maxwell, & Miller, 1967), Lawer (Lawler, Lenstra, & Kan, 1993) and Vignier (Vignier, Billaut, & Proust, 1999), studied the diversity of works characteristics and machines as well as the variety of optimization criteria to which the models could be subjected. Their studies yielded a high planning models number which needed to be cataloged in some way, giving rise to several nomenclatures to define these problems. One of the most used nomenclatures is the one proposed by Graham (Graham, Lawler, Lenstra, & Kan, 1979). This nomenclature refers to the three-parameter the problem classification, which consists in three variables $\alpha / \beta / \gamma$.

- α : is the field that describes the machine environment and may contain more than one entry.
- β : is the field that provides details of the processing characteristics and restrictions. You can have, one, multiple or no entry.
- γ : is the field that identifies the target to be optimized and usually contains a single entry. In multi-objective optimization cases, it may contain more than one entry.

The aforementioned scheme has been widely accepted by researchers and specialized literature. The investigations carried out in recent years incorporate extended versions of this nomenclature so that it is classified as open. (Blazewicz, Ecker, Pesch, Schmidt, & Weglarz, 2007) (Pinedo, 2008) (Brucker, Scheduling Algorithms, 2007)

In general, most *Scheduling* optimization models aim to reduce the maximum path (makespan), it is not more than the completion time of the last operation or the time necessary to complete all the works.

(1)
$$Cmáx = máx_j \in \{1...n\}C_j$$

Although this is one of the most used, there are other criteria such as the total flow (F_{max}), machine leisure (*Idle*), delay (L_j), tardiness (T_j), advanced jobs number and back jobs number (NE_j and NU_j). This list includes one of the most recent criteria: energy consumption (E_c). (Márquez Delgado, 2012)

Authors address the issue in question agree that the treated models are related *Job Shop Scheduling* and *Flow Shop Scheduling Problems* (Herrera Márquez, 2015), (Fonseca Reyna, 2012), (Campos López, 2008), (Fernández-Baños MarÍn, 2003), (Mailing, 2003), (Solano Charris, 2008), (Tellez Enríquez, 2007), (Constantinescua, Francalanzab, & Mataraz, 2014), flexible systems models are also addressed (Teekeng & Thammano, 2012), (Özgüven, Özbakır, & Yavuz, 2010), but it should be noted that there are few researches that refer to reconfigurable systems (Azab & Naderi, 2014).

As previously discussed, the modeling systems objective is to study them and decompose them into subsystems that allow a better understanding of them. For researchers who perform the modeling of these systems it is practically impossible to take into account 100% of elements that interact with it. Due to this, it is necessary to set operating set restrictions that may be related to the capacities as a function of time and / or the resources that are counted, the operations sequences or the elements to be optimized by the model.

These restrictions that condition the models and turn the investigation, allow a better studied systems understanding in exchange for their simplification. The above allows sometimes incurred in obtaining results that differ from actual systems behavior.

Then and relate a total of twenty (20) restrictions which were found in the models studied. It should be noted that the model studied that had the most restrictions had a total of thirteen (13) and that on average optimization models have approximately five (7) restrictions, although this does not constitute a general rule.

Restrictions most used in optimization Scheduling problems models.

- 1. There is only one machine of each type; there are not several machines to perform the same operation.
- 2. There is only one job of each type, so these are different from each other, this rules out the presence of work lots.
- 3. A machine can only process one job at a time.
- 4. The technological restrictions (technological path) are known and invariable.
- 5. Each job is an entity and therefore two operations of the same job cannot be processed simultaneously.
- 6. There is no interruption, that is, each operation once started must be completed before starting another operation on the same machine.
- 7. Each job includes one and only one operation on each machine, so all jobs contain an operations number no greater than the machines number. This means that there is no recirculation.
- 8. The process times are independent of the sequence followed, which excludes the adjustment times in the machines according to the work sequence considered or the transport times between machines.
- 9. All the data involved are known and fixed: jobs number, machines number, and time of operations among others.
- 10. The processing times in the different machines are known and fixed.
- 11. All jobs have the same probability of being programmed.
- 12. The works are available to begin processing at the initial instant (t = 0).
- 13. All the machines are ready to process the jobs at the initial instant (t = 0).
- 14. Once the execution of an operation is finished on any machine, it is automatically available to receive the next operation. The presence of *buffering (buffers)* between the machines is not considered.
- 15. A job is considered finished at the moment when all its operations have been completely processed.
- 16. The reference change times are known and independent of the processing order.
- 17. The machines may be idle at any time in the plan.
- 18. We do not consider the existence of reconfigurable machines.
- 19. No operation has priority over another.
- 20. Each job must go through all the machines before it is completed.

The figure shows the relationship between the twenty (20) restrictions formulated previously and the models consulted.

If the graph is analyzed, it can be seen that a common restriction in most models is # 3 and it refers to the machines technological capacity, which can only do one job at a time. Very close to this is the restriction # 5 which talks about the simultaneously impossibility executing two operations of the same job, since each job constitutes an entity.

Coupled with this, restrictions # 4 and # 6 indicate the technology route existence, that is known in advance and its compliance is mandatory. It is necessary to take into account that once an operation described in the route has been started, it must be executed without interruptions, so the following operation will not start until the one that is running is finished.

In case of restriction # 1, it can be said that it appears as one of those referenced due to the particularity of its condition. The single machine existence of each type makes it possible to simplify the model exponentially, which facilitates the researchers work so this restriction is found in a large part of the optimization models.

On the other hand, there are restrictions that are not taken into account as are the cases of # 7, # 14, # 18, # 19 and # 20.



Figure 2 Graph of relations between models and restrictions.

In case of # 7 only found a job that gives treatment to it. The research proposed by Herrera Márquez (2015). This restriction addresses the parts recirculation within the system, which indicates that a job can visit a machine on more than one occasion, a situation that occurs very often in conventional workshops. By eliminating, in its study, this restriction, the author annuls the argument that the work existence should not be greater than the machines number, in order to avoid recirculation.

Restricting # 14 emphasizes the availability of each machine once every operation is completed, so that ignores the existence of temporary storage in the intermediate process. This characteristic prevents taking into account batch production systems, one of the most practical ways of carrying out productive processes.

In addition, there are few works analyzed that include the two types of flexibility, partial and total, a characteristic that is inherent in the *FMS* and the *RMS*. This condition can be coupled to restriction # 18, which limits the existence of reconfigurable machine tools in the models analysis. The shortcomings of these elements in this studies type, at a time when reconfigurable manufacturing systems constitute an organized and production efficient, constitutes the turning point for the future research development.

The conceptualization of these restrictions also relates to # 8, which appears in fourteen (14) of the twenty-three (23) models analyzed. His restriction states that the process times are independent of the sequence followed, which allows researchers not to contemplate within the models the machine settings times or the transport between them.

The practice shows that it is much richer than the theory, then, both in mechanized workshops as in any type of production line that has machine tools or some equipment type to perform operations is necessary to make the said machines adjustment and take into account the reconfiguration possibility or readjustment in breakage case. Likewise, the most common practice in production systems is the batches production of products that streamline the process and prevent the accumulation of large inventory amounts, this criterion is subject to the production systems characteristics, but is applicable to the machining workshops. In addition, however well distributed the workshop is, it will always be necessary to invest a time minimum to move the work from one machine to the next.

If we take into account the above, as well as the development achieved level by the manufacturing systems, especially the *RMS*, the need to develop research that allows the production processes optimization in workshops that have reconfigurable machine tools becomes relevant. This must be based on the efficient models integration that are able to assimilate the systems behavior if they include in these the configuration times and adjustment of the *RMT*.

1.3 Conclusions

From the review and analysis of the literature consulted specialized in the subject under study, it is possible to arrive at the following partial conclusions:

The reconfigurable manufacturing systems development based on the use of reconfigurable machine tools assuming rapid capable changes in the product demand of their characteristics, as well as their design focused on compatibility with the group technology philosophy, constitutes a valuable tool for the current manufacturing systems.

The wide classification range existence of *scheduling* problems allows its identification with various production sectors and services, among which can be mentioned manufacturing processes in conventional machining workshops.

The models development for the *scheduling* problems optimization has shortcomings in the analysis of the reconfigurable machine tools existence and the inclusion of the configuration and said machines adjustment times.

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