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Integral Approaches to Integrated Scheduling

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1. Introduction

The objective of this chapter is to address integrative views to production scheduling problems. These views are relative to constraining resources integration in the problem formulation, cost components integration to guide optimization and solution methodologies integration to achieve computational performance. We reconsider the widely used models and representations for production scheduling problems, we review optimization objectives and we discuss and propose efficient solution approaches to the production scheduling problem.

Traditionally, machines are considered to be the only constraining resources when solving a production scheduling problem. This representation although resulting in high mathematical complexity, does not reflect the real problem. Many other constraining resources are needed in a production setting. Among these are material handling resources, buffers, route segments and intersections on a shop floor, labor, tools, pallets, fixtures and energy. Rich formulations considering these resources were presented in the literature together with corresponding solution approaches. These formulations are frequently referred to as the integrated scheduling problem. We provide an overview of these formulations within a proposed framework that builds on special characteristics of the different resources needed. Objective functions guiding optimization are also revisited for relevance analysis. Moreover, a generic cost function integrating different components is proposed. It unifies and complements, in some cases, most of the objective functions proposed in the literature.

This rich picture is not without cost. The corresponding formulations result into very high mathematical complexity and exact solutions become difficult. Literature analysis as well as our research in this area reveals the importance of integral approaches to tackle such problems. Integral approaches may combine different methodologies whether at the level of the algorithm development subsuming one method into another or at the level of solvers cooperation for sharing information or at other levels of integration. Among methodologies considered and being integrated together are mathematical programming, constraint programming and metaheuristics. An integration scheme is proposed and performance of approaches is analyzed.

The high cost of integration suggests a prudent approach to the integrated scheduling problem. Resources to integrate, objectives to consider and methodologies to use remain questions to answer according to the industrial reality studied. We conclude with a proposition of a methodology for diagnosis of a scheduling problem that allows tackling the problem, at first, by the most appropriate formulation. This methodology proposes

measures for identifying critical resources involved in a production process.   Section 2 presents integrated scheduling problems, section 3 reconsiders the widely used optimisation objectives and provides a new cost function, section 4 discusses integration schemes, section 5 presents integral approaches for solving the problem, section 6 elaborates on a diagnosis methodology for the problems and the conclusion is presented in section 7.

2. Integrated Scheduling Problems

Scheduling tasks on machines in production scheduling problems is addressed in a hierarchy of decision making following the production planning problem. At a lower level, scheduling decisions relative to other resources are made. The advantage of this approach is to be able to tackle problems of reasonable size. However, this approach results in suboptimal solutions.
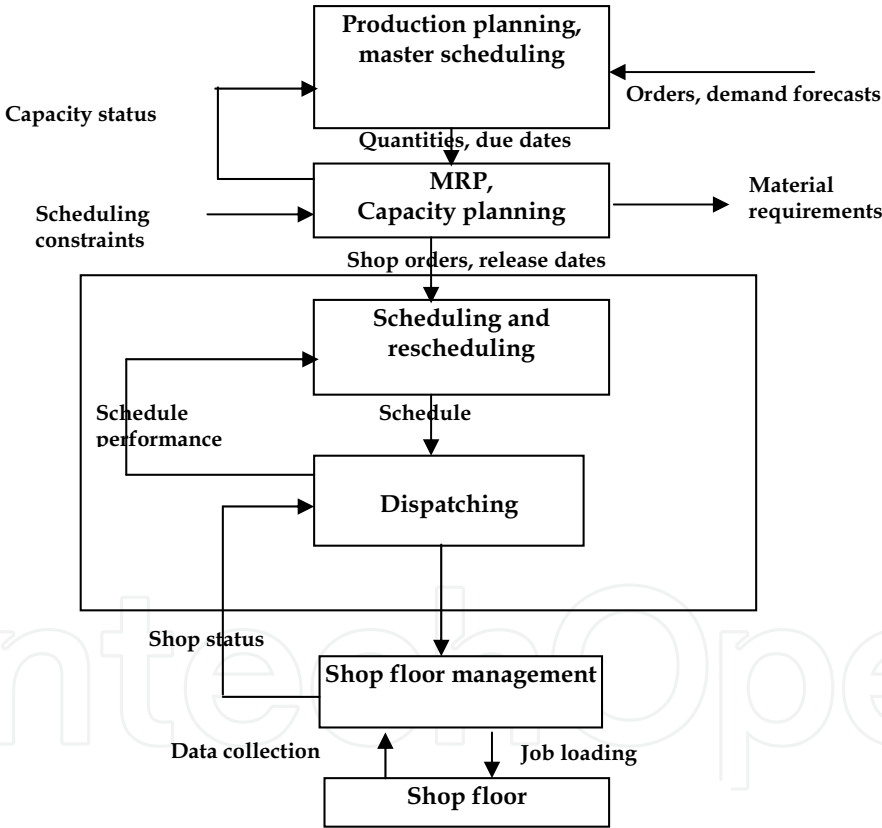

Figure 1. Information flow diagram in a production system (Pinedo, 1995)

Ideally, we would integrate different levels of decision making when this is possible and necessary. The example is integrating scheduling and planning decisions. We refer to this as

multi-level integration. At the scheduling level, integrating all influencing factors and resources allows the calculation of a realistic schedule. We refer to this as single level integration. Here, the level is the scheduling level. One multi-level integration problem is the simultaneous lot-sizing and scheduling for single machines. A review on these problems was presented by Elmaghraby (1978). Since then a number of researchers studied the problem. Simultaneous determination of lot sizes and dynamic sequences for several products in a single machine environment with capacity constraints was studied by Salomon et al. (1991), Cattrysse et al. (1993) and also by Glass (1992) who considers only the three products case. Pinto and Rao (1992) studied the same problem in a flow shop setting with capacity constraints. Heuristic solution methods were proposed.

The job shop problem was also approached with a more integrative view by Wein and Chevalier (1992). The authors consider three decisions to optimize at a time: fixing due dates for jobs, launching jobs on the shop floor and sequence determination. A two machine shop is considered. Lasserre (1992) considers an integrated model that addresses simultaneously planning and scheduling problems in job shops. A decomposition procedure alternating between the two problems is used to solve the integrated problem.

2.1. Resources needed in the production process

We focus in the following paragraphs on the single level integration. Single level integration considers influencing resources when solving a scheduling problem. Influencing resources include material handling equipment, buffers and tools. Neglecting these resources assumes an infinite capacity for all of them. It also underestimates the interdependence between the different resources.
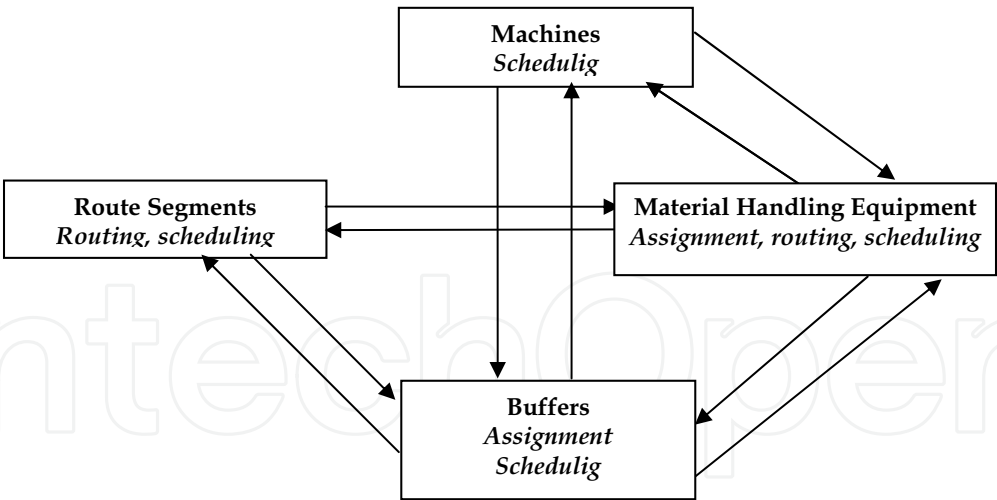

Figure 2. Mutual influences and decisions related to production resources

The different hierarchical decision making models do not include decisions relative to a number of resources influencing a schedule. Decisions related to handling equipment, to buffers and to tools are not enumerated in an explicit manner. Consequently we neglect an

important number of constraints and decisions in order to be able to present a solution to the scheduling problem. Neglected constraints are sometimes addressed in a second separate problem or in the same problem. However, this is done at a later stage after calculating machine schedules.

Scheduling decisions incorporating tools can be studied in light of contributions in production scheduling with resource constraints. These contributions consider resources to be used in the same time during the machines operation. This is also the case of raw materials. In the case of integrating the material handling equipment, production scheduling with resource constraints literature does not offer much help. Machines and the material handling system have different interdependence relations. Handling equipment, buffers and route segments are used before or after transformation on machines. Precedence constraints are to be respected and dead heads have to be accounted for.

Material handling system design and operation including scheduling, routing and assignment was studied in the Flexible Manufacturing Systems literature. Flexible Manufacturing systems include Automated Guides Vehicles that are costly investments and bottleneck resources in many cases. In these problems, handling requests are determined by the machine schedules. In some cases, the problem is reduced to a vehicle routing problem that was extensively studied in the literature and for which small instances are solved efficiently.

C_{max} is a very common objective to optimize in the scheduling literature. The material handling scheduling can be used to further optimize this measure. Some authors studied realistic scheduling problems where production lots are not equal to transfer lots. The idea is to devise production lots in sub-lots to enable overlapping of operations. Potts and Baker (1989), study the transfer lots for a flow shop problem in single and multi-product cases. Vickson and Alfredsson (1992) consider this problem for two and three machines flow shops. They study the objective of minimizing the total flow time. Trietsch and Baker (1993) study a transfer lots problem with material handling equipment capacity constraints. Glass et al. (1994) study the single product problem in flow shops, job shops and open shops. Sriskandarajah and Wagneur (1998) consider this problem in a no-wait two machines flow shop in the case of multi-products. Esaignani et al. (1999) consider the same problem in an open shop environment. Langevin et al. (1999) calculate the transfer lots in a flow shop for minimizing all relevant costs. Among all these contributions, only Trietsch and Baker (1993) consider a finite capacity for the handling equipment when studying the transfer lots problem. Langevin et al. (1996) consider a cost associated to the utilization of handling equipment with no capacity constraints.

Now that the integration of decisions is clear, we present in a concise fashion in table 1 the major contributions in the literature that addressed the integrated scheduling problem. We consider single level integration incorporating basically material handling resources. These resources are of special importance as discussed above. They may also represent most of the constraining resources in a certain reality. For example, Lau and Zhao (2006) develop a joint approach to solve the problem of integrated scheduling of different types of material handling equipment in a typical automated air cargo handling system where schedules for different cooperating equipment are highly interactive. Finally, it is worth noting that all the contributions address single objective optimization. However, Reddy and Rao (2006) recently solved a multi-objective integrated scheduling problem in a flexible manufacturing environment using evolutionary algorithms.

Nb.	1	2	3
Author	Raman et al. 1986	Sabancuoglu and Hommertzhein (1989)	Jaikumar and Solomon (1990)
Problem	Int-Sch FMS-FS-Sta FMS-FS-Dyn	ES-Scheduling rules for machines and AGVs-JS	FMS-Dyn
Routing Options	N/A	N/A	Bidir-Seg
Processing/ Handling times	N/A	N/A	N/A
Nb. Mach.	N/A	6	33 Cells
Nb. And type of material handling equipment	N/A	2 AGVs	20 AGVs
Layout	N/A	Cellular	50 cells for assembly, machining, shipping and receiving in two big squares
Nb. Of operations/ job	N/A	1 to 6	N/A
Nb. of jobs	N/A	N/A	200 types of pieces
Methodology	IP- BB, approach was extended to the dynamic case	Simulation under several conditions	1.Machines scheduling 2.Time-Space network 3- Minimal decomposition of the network chain determines the assignments and the number of AGVs.
Objective	Min $\sum T_j$	Due date objectives	1. Max machine utilization 2. Min total handling time 3. Min the AGVs fleet
Special characteristics	Return to L/U station after each handling task.	Jobs number and content simulated	Return to L/U station after each machining task

BB   Branch and bound
FS   Flow Shop
JS   Job Shop
N/A   Not Available

Undir-Seg   Unidirectional Segment
FMS   Flexible Manufacturing System
Sta   Static
T_{ij} Duration of Material Handling Task

Legend for the table 1

9	8	7	6	5	4
King et al. (1993)	Sabuncuoglu and Hommertzheim (1993)	Sabancuoglu and Hommertzhein (1992b)	Sabancuoglu and Hommertzhein (1992a)	Blazewicz et al. (1991)	Blazewicz et al. (1991)
Int-Sch in a cell- FS	ES- Scheduling rules for machines and AGVs – JS.	ES- Scheduling rules for machines and AGVs - JS.	ES-Scheduling rules for machines and AGVs- JS.	Int-Sch	Hier-Sch
Unidir-Seg	Unidir-Seg	Unidir-Seg	Unidir-Seg	Unidir-Seg	Unidir-Seg
P_i= 1 to 9 UD T_{ij}= 3 to 7 UD	P_i : Several distributions T_{ij} : Several speeds	Uniform & Exponential Distributions	Normal Distribution	P_i=1 to 2 T_{ij}>0.5 <3	P_i=1 to 2 T_{ij}>0.5 <3
2	6	6	6	3	3
1 Robot	2 AGVs	2 AGVs	2 AGVs	2 AGVs	2 AGVs
Line	Cellular	Cellular	Cellular	Loop	Loop
2	1 to 6	1 to 6	1 to 6	1	1
5 to 25	3000 were simulated	N/A	3000 simulated	9	9
MIP-BB	Simulation	Online dispatching algorithm using several priority rules	Investigation by simulation. Several conditions tested	Pseudo – polynomial algorithm based on DP	1.Machine scheduling 2. Solving a VRP with time windows.
Min C_{max}	Due date objectives	Mean flow time and mean tardiness	Mean flow time	Min C_{max}	Min C_{max}
A finite number of jobs	Jobs arrival follow a PD	Jobs arrival follow an ED	Jobs arrival follows an ED	Identical machines	Identical machines

14	13	12	11	10
Geiger et al. (1997)	Ioachim and Sanlaville (1996)	Bilge and Ulusoy (1995)	Lee and DiCesare (1994)	Lee and DiCesare (1994)
Int-Sch	Int-Sch Repetitive and multi-pieces	Int-Sch JS	Int-Sch JS	Int-Sch JS
-----	-----	Unidir-Seg	Bidir-Seg 2 direct paths between machines	Bidir-Seg 2 direct paths between machines
UD Average= 6.67	An approach applicable for all data	P_i= 3 to 21 T_{ij}= 2 to 20	P_i= 1 to 23 T_{ij}=8 to 20	P_i= 1 to 23 T_{ij}=8 to 20
12 basins	M	4	3+ 1 machining robot	3+ 1 machining robot
1 Robot	1 Robot	2 AGVs	5 AGVs	5 AGVs
Line	Robotic cell Line	Process	N/A	N/A
6 to 12	-----	<=5	<=3	<=3
10 to 50	------	5 to 8	<=4	<=4
A tabu method	Formulation as the repetitive central problem of Carlier and Chretienne (1988). Longest path algorithm	MNLP and a time window heuristic	Petri net model	Petri net model
Min C_{max}	Min cycle time	Min C_{max}	Min C_{max}	Min C_{max}
No wait constraints, blockage and limited buffers	Results extended to multi-robot cells		AGV dedicated to a machine 2 AGVs dedicated to L/U	AGV dedicated to a job Return to L/U

19	18	17	16	15
Sabuncuoglu and Karabuk (1998)	Anwar and Nagi (1998)	Ulusoy et al. (1997)	Crama (1997)	Anwar and Nagi (1997)
Int-Sch JS	Int-Sch Assembly	Int-Sch JS	Review on the integration of material handling, tools and machines resources	Int-Sch Assembly
N/A	Unidir-Seg	Unidir-Seg	----	N/A
2-Erlang Distribution	P_i= 5 to 10 of UD T_{ij} = Several ratios	P_i= 8 to 20 T_{ij}= 5 to 21	-----	N/A
6	2 to 9 cells of 1 to 3 machines	4	-----	N/A
3 AGVs	1 to 3 AGVs	2 AGVs	-----	AGVs
Cellular	Cellular	3 Process	----	Cellular
5 to 6	5 to 10 for pieces to manufacture	2 to 4	-----	N/A
25	Total of 12 to 239 pieces, 12 to 126 pieces to manufacture	5 to 30	------	N/A
Partial Enumeration	Heuristic	Genetic algorithms	Proposition of some combinatorial optimization models.	Heuristic
Min C_{max}	Min C_{max} Cost objectives	Min C_{max}	Several	Just in time
Central buffer to prevent blockage	No details on process plans	Average deviation from optimal =2.53% for test problems	A representative review	No numerical results

Table 1. Contributions in integrated scheduling

22	21	20
El Khayat et al. (2006)	El Khayat et al. (2003)	Sabuncuoglu (1998)
Int-Sch JS	Int-Sch JS	ES-Int-Sch rules for machines and AGVs- JS
Bidir-Seg	Bidir-Seg	Unidir-Seg
P_i= 3 to 21 T_{ij}= 2 to 20	P_i= 3 to 21 T_{ij}= 2 to 20	ED
4	4	6
2 AGVs	2 AGVs	2 AGVs
Process	Process	Cellular
<=5	<=5	1 to 6
5 to 8	5 to 8	2000 simulated
Mathematical programming and constraint programming formulations solved optimally	Mathematical programming and constraint programming formulations solved optimally	Simulation
Min C_{max}	Min C_{max}	Mean flow time
	Conflicts considered	Jobs arrival follows an ED. Break downs considered

3. Optimization Objectives

In this section we discuss the relevance of the objective functions of scheduling problems formulations presented in the literature. We also present a decomposition of the different relevant production costs. This cost decomposition helps in the formulation of more realistic optimization objectives for practitioners.

Scheduling literature mostly addresses classical problems defined since the 1950's. Too little analysis of the relevance of constraints and objectives has been done. Formulations lack richness and do not represent the industrial realities. This observation was supported by Browne et al. (1981).

Formulations naturally include constraints and objectives. These differ according to the setting studied. Often, all constraints are not formally considered. Some of these are addressed in an approximate manner at a lower level in the decision making. In the integrated scheduling problem addressed by a number of authors classical objectives are often used. We mean by classical objectives; system objectives and due date objectives (Graves et al. 1981).

3.1 Common Objective Functions

Commonly used objectives in the production scheduling literature include:

- Minimize the makespan (C_{max})
- Minimize the maximum tardiness (T_{max})
- Minimize the total tardiness (ΣT_j)
- Minimize the total weighted completion times ($\Sigma w_j C_j$)
- Minimize total completion times (ΣC_j)
- Minimize the total discounted weighted completion times $\Sigma w_j(1-re^{-rc_j} dt)$
- Minimize total weighted tardiness ($\Sigma w_j T_j$)
- Minimize the number of tardy jobs (ΣU_j)
- Minimize the weighted number of tardy jobs ($\Sigma w_j U_j$)

Objectives used in material handling scheduling problems are also numerous. Examples follow:

- Maximize throughput
- Minimize dead heads
- Maximize the utilization or the average utilization of material handling equipment
- Minimize the number of utilized equipment
- Minimize the average flow time for jobs
- Maximize the production volume or the average production volume (average number of finished jobs)
- Minimize the maximal length of queues
- Minimize the average waiting time
- Minimize the total traveled distance = Minimize the transportation time
- Minimize the jobs completion time
- Minimize the total lateness
- Minimize the makespan
- Minimize the number of tardy jobs
- Minimize the work in process

Most of the literature addresses mono-objective problems. Bagchi (1989) solves a multi-criteria single machine problem. Other researchers also solved multi-criteria single machine problems. However, material handling system constraints were not considered. This situation proposes that the problems addressed corresponded to a certain reality of interest to practitioners and researchers in this period of time. Since then, objectives were not reconsidered. Objectives need to be reviewed in light of the practitioners needs. Complexity of scheduling problems has always attracted the researches attention to the development of better solution methods without giving enough attention to the compatibility and relevance of the objectives. Very few contributions discuss the compatibility of these objectives and objectives addressed by practitioners in industry. Another problem related to the objectives

is the place of the objectives in relation to constraints as well as the place of the constraints in relation to the objectives.

In 1973, Holloway and Nelson argued that problems formulated in the literature are tackled in a different way than that of practitioners. According to the two points of view the formulation of constraints and objectives is mixed up. The article presents an example of a job shop scheduling problem with the objective of minimizing lateness subject to the constraints of respecting the machines capacity and respecting the precedence constraints among tasks. The authors propose two alternative formulations describing the same problem according to the different points of view. The first formulation presents a practical point of view:

- minimizing the necessary resources or the overtime for meeting the orders subject to due date and precedence constraints.

    The second formulation is interesting for solving purposes:

- minimizing the precedence constraints violations subject to due date and machines capacity constraints. If we find a solution for this formulation without violating the precedence constraints, we will provide eventually an optimal solution for the initial formulation of the problem. This second formulation has also allowed the development of a heuristic to solve the problem. Good solutions were obtained with the heuristic. The test problems size was very limited (up to 7 machines and 14 jobs). To our knowledge, this review of the relevance of scheduling problems formulations was not readdressed in the literature.

The first proposed formulation among these two reflects an important point of view. In industry, we should respect the due dates according to a cost to be determined. Using over time is sometimes inevitable. In some cases, we may also need subcontracting.

The idea of the second formulation proposes solving a constraints satisfaction problem, which can be done by constraint programming methodologies. This technique is very effective for solving constraint satisfaction problems and it very much fits the above presented formulation.

Among the interesting objectives considered for the scheduling problems are the "just in time" objectives which target the minimization of the lateness as well as the earliness of jobs in production (Biskurp, D. and Cheng, T.C.E., 1999). The rationale behind the formulation of this objective is to save inventory costs as well as lateness penalties. This view to the problem proposes the consideration of important costs throughout the production process. However, the real problem would be to respect the due dates while minimizing the costs related to inventory and supplementary resources if needed. Hence, a compromise must be worked out among different relevant costs. The objective of minimizing costs related to the functioning of the production system, which is rarely studied (Lasserre, 1992), would be more practical and relevant. This formulation considers a production unit cost, an inventory cost, a stock out cost and a setup cost. The problem formulation covers a number of periods.

Objectives related to cost optimization are generally used in planning models for calculating the production lots. They are not commonly used in scheduling problems. McNaughton (1959) presents an objective of minimizing the total linear lateness costs for a single machine problem, which is equivalent to minimizing the total lateness.

3.2 Cost Functions
The definition of an optimization objective for a scheduling problem reflects a certain cost that is considered the most important. For example, when minimizing the makespan, we

minimize an idle time for equipment and workers and hence we minimize a cost to the enterprise. Minimization of the total lateness or the maximal lateness also reflects a cost that would be related, for example, to

- the loss of a client
- the cost of a more expensive shipping alternative in order to respect due dates.

It would be interesting to consider direst, indirect, penalty and opportunity costs which were not presented in a complete fashion in problems formulated in the literature. However, it is important to attribute adequate coefficients to the different costs to obtain a total significant cost. This demands an estimate for the different costs.

Costs incurred by manufacturing firms were identified by Lovett, JR., (1995):

- cost of engineering, design and development
- manufacturing manpower
- cost of equipment and tools
- cost of material
- supervision
- cost of quality assurance, control and tests
- cost of shipping and receiving
- cost of packing
- cost of handling and inventory
- cost of distribution and marketing
- financing
- taxes and insurance
- overheads
- administrative costs

Among costs listed above, only some are directly related to the scheduling problem. The other costs are incurred by the firm regardless the production schedule in place.

The relevant costs are listed hereunder with proposed definitions and notations:

- **manufacturing man-power.** A total cost is considered with direct components and indirect components like training and social benefits. We consider only one rate for operators of a certain type of equipment. Differences related to competence or seniority are not considered.

Cost of manufacturing man-power = MP (r) + MP (sr) +MP (sf)

MP (r)   = regular man-power

MP (sr) = overtime for manpower during the working days

MP (sf) = overtime for manpower during the weekends

Cost related to operators should be calculated according to shifts in the industry to allow for calculations of overtime or supplementary workforce. If we suppose that the calculated schedule is of z time units length, we may consider that the first x time units represent the regular time (corresponding to the shift) and that the following y time units represent the overtime.

The hourly rates of the manufacturing manpower differ according to the operators specialty (respective workstations: packaging, test or other), and their functions. Hence, a supervision cost can be envisaged.

- **Cost of equipment and tools (utilization cost/unit time).** Cost of acquisition, depreciation and inflation are included in this cost. Idle time of equipment is not to be estimated and it is among decisions to be made at other levels.

Un extra cost for using production or material handling equipment is reflected by expenses of more frequent maintenance activities, after a certain number of utilization hours. For a schedule that includes y extra time units we consider the following incurred cost:

$$(y/nbHM)* CM$$

where nbHM = number of allowed working hours of the equipment before doing the maintenance.

CM = maintenance cost for the equipment.

Stretching the schedule increases maintenance costs because equipment remains working even if part of the time is considered idle from the production point of view. Maintenance may also impose the need for extra equipment.

- **Material handling cost.** In addition to the cost generated by operation overtime, maintenance, system supervision and eventually operators, there is a cost corresponding to the traveled distance.

For an order, we should minimize: Dt * Cp

where Dt = total distance traveled in shop.

Cp = cost of traveling one unit distance.

- **Inventory cost.** Orders being processed represent work in process inventory which is a cost to the enterprise corresponding to the flow time in the workshop. Raw material with a less value added cost less than almost finished products. Meanwhile, products quitting the system generate money which is considered a source of financing. Possession of products also represents an immobilized capital and hence an opportunity cost. To simplify the cost calculation, we can consider only three inventory costs, even if we reach different levels of added value during the product flow time in shop.

CsRM= raw material inventory cost

CsWIP= work in process inventory cost

CsFG= finished products inventory cost

Other costs are to be included:

- **Lateness penalties.** The lateness penalties are evaluated according to contract terms and they can reach double the value of an order. This cost is related to a promised level of service and it can eventually correspond to the loss of a client.
- **Setup cost.** This cost is to consider when production maybe interrupted It corresponds to time where production is stopped and where specializes operators are solicited for the setup operation.
- **Pallets cost.** This cost becomes important when we consider several transfer lots. We can also consider a utilization cost as function in time.
- **Opportunity cost.** an unnecessarily lengthy schedule including a number of idle time units represents an opportunity cost the same way as immobilized capital.
- **Extra cost** generated by a shipping option to respect due dates.

We have here tried to limit the costs to those related to the scheduling problem. It is clear that relevant cost exceed the shop floor limits. It is important to estimate these cost elements but this is naturally context dependant. Our integration scheme is formalized in the next section and literature contributions are presented.

4. Integration Schemes

As the title of this chapter suggests integration can be viewed from different angles. We are developing three integrative views for the scheduling problems in this chapter; namely:

- resources integration;
- cost elements integration and
- solving methodologies integration.

In our opinion these three dimensions offer an integration scheme in light of which a scheduling problem should be analyzed, formulated and eventually solved. However, we cannot leave the reader with the impression that there was no effort in structuring the integration concept and offering some schemes for a wide variety of optimization problems. We present two important classifications that address the integration and the hybridization concepts.

The first classification structure is proposed by Jacquet-Lagrèze (1998). The author recognizes different types of hybridization and categorizes them based on the looseness or tightness of integration. The categories are:

- **Organizational Decomposition:**

The organization or end-user considers the problem within the organizational structure of the company and solves the corresponding sub-problems. In some respect the overall problem is computationally too difficult to be solved as a single problem, although there would be benefits in doing so.

- **Complexity Decomposition:**

The model is too complex to be solved as one with current software and hardware technologies. It is therefore broken into sub-problems, small enough to be solved by a single technology. The problem-solving team may also be split for each sub-problem.

- **Hybrid Decomposition:**

For efficiency reasons sub-problems may be solved using two or more models with associated algorithms co-operating and exchanging information.

Little (2005) proposes the following classification structure:

- **One Technology Subsumed in Another**

One technology, or aspect of it, is subsumed within a more dominant solving technology to enhance its performance. This is the case with Branch and Cut (Balas et al., 1996), which is based on a B&B search, but enhanced at each node with cutting plane techniques.

- **Problem Decomposition**

Decomposing the problem into separated modules, and then solving each part with a different technique. Here, the techniques collaborate by passing the results of applying the first technology on to the second.

- **Independent Solvers**

Solvers share information obtained by running each technology. Here one solver is run to some point, and then information is passed across to the other solver. In this way, each solver has its own model and retains its own character and strengths. However, it still uses aspects of the other in the form of information about the problem.

These two schemes present a number of similarities. Organizational decomposition and problem decomposition can be viewed as being more or less the same. They represent an aggregation for both resources decomposition and cost elements decomposition that were important to detail earlier in a way that encompasses the scheduling problems reality. The resources decomposition and the cost elements decomposition were hence two essential

views that merited analysis. That is why they represent two distinct elements in our proposed scheme.

5. Integral Approaches for Solving Integrated Scheduling Problems

The last section showed that efficiency entails that models and algorithms cooperate for exchanging information. It also showed that technologies can be integrated through subsuming for enhancing performance. Getting back to the developments of section 2, it will be two pretentious from our side to try to draw conclusions on possible hybridizations or integrations. This would be imposing constraints on ideas and avenues for integrating approaches since different realities may suggest a variety of approaches. In lieu of this we will present some observations regarding the issue.

We observe that the complexity of the problem should orient our attention to metaheuristics in solving the integrated scheduling problem with efforts in hybridization. Genetic algorithms were used in this regard. Zhou et al. (2001) used a hybrid approach where the scheduling rules were integrated into the process of genetic evolution. Tabu search was less used for integrated scheduling problems and other metaheuristics are not yet enough exploited. Hybridization among these methodologies can be envisaged.

Hybridization among operations research techniques and constraint programming techniques is one of the most promising avenues for this class of problems. For more on the issue, Hooker and Ottosson (2003) and Milano (2004) present interesting developments. Contributions using constraint programming mostly employ general purpose propagation algorithms. A research effort is needed for developing efficient propagation algorithms for this class of problems. This will also help in the hybridization efforts. For an introduction to constraint programming and for applications in scheduling the reader is referred to Mariott and Stuckey (1998), Hooker (2000) and Baptiste et al. (2001).

It is clear that hybrid approaches can be used on the methodological level to solve scheduling problems, but this is not all. At the implementation level hybridization can be thought of from a tool box perspective. A scheduling support system might include a number of programmed methodologies that the practitioner may use as appropriate depending on the data or the size of the problem. These methodologies can also cooperate in sharing information. This approach was used by El Khayat et al. (2003) and El Khayat et al. (2006) where separate methodologies were used to solve the same problem as appropriate.

6. Diagnosis Methodology

As developed earlier, production scheduling problems posed in the literature do not correspond to what we find in real facilities (Browne et al. 1981). In general three paradigms are used to tackle scheduling problems: the optimization paradigm including simulation and artificial intelligence among other techniques, the data processing paradigm and the control paradigm (Duggan and Browne 1991). The preceding literature analysis mainly focused on the first paradigm with a focus on realistic formulations and solution methodologies for production scheduling problems. This involves integrating resources that were generally neglected in solving scheduling problems. Machines and material handling network with all its corresponding resources: vehicles, route segments, intersections and buffers are all constraining resources. The more resources are integrated, the more complex

the problem becomes and the more difficult it can be solved. However, affirming difficulty should not discourage tackling the problem in a rigorous fashion.

We think it is important to propose to practitioners in industry a diagnosis methodology for scheduling problems. This methodology should include an analysis and an evaluation step of the criticality of resources to better identify the elements necessary to include in the problem formulation. With the actual limits of available solving technologies, integrating the whole reality in a formulation may allow efficient solving of some very special cases. We think of equal processing times and simple precedence relations. This is to be confirmed through tests. This diagnosis should be undergone with simple and effective means of decision support. It should specify the formal problem to be addressed. To illustrate this methodology, we present the following figure where we try to answer three questions.

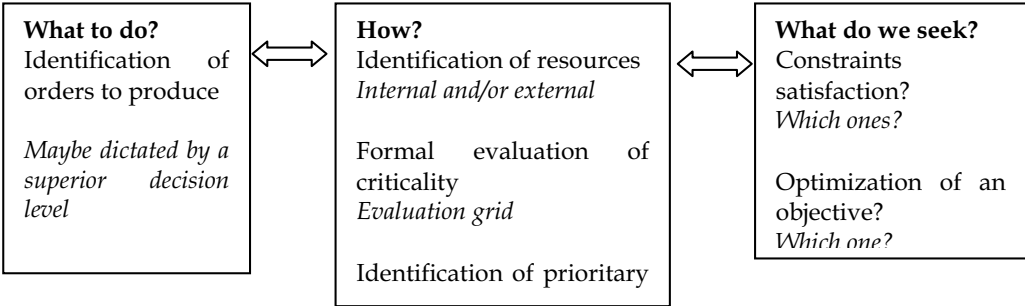| **What to do?**	**How?**	**What do we seek?**
Identification of orders to produce	Identification of resources *Internal and/or external*	Constraints satisfaction? *Which ones?*
Maybe dictated by a superior decision level	Formal evaluation of criticality *Evaluation grid*	Optimization of an objective? *Which one?*
	Identification of prioritary	

Figure 3. Diagnosis methodology of a scheduling problem

This methodology proposes a simplification/decomposition of the scheduling problem and to consider a part of it at a second level of decision making. Evidently our objective was to integrate the decisions and the decomposition we are proposing is different and thoughtful. A classical decomposition approach would be to formulate the integral problem incorporating all resources and then propose decomposition at the level of the solution methodology. In this case we target the model structures without considering data such as task durations, resources and precedence relations determining the criticality of a resource or punctual criticality phenomena. Decomposition based on the problem definition and data analysis seems promising and prevents either over-estimation or underestimation in the choice of a solution methodology. In other terms, this prevents simplifying the models if this penalizes and complicating them when it is not rewarding.

However, proposing a resources criticality evaluation grid for a scheduling problem is not an easy task. This evaluation should give quick and relevant information on the important part to consider in the first place when solving a difficult problem. We should not solve the whole problem to get this information. We should be able to measure criticality with quantifiable indicators. This information will help propose the appropriate formulation for a scheduling problem. We think that starting with a formulation integrating the most critical resources is the first determinant factor of efficient and satisfactory solving of a scheduling problem. Critical resources differ according to different realities. This might give rise to interesting methodological approaches.

7. Conclusion and Future Research

In this chapter we have tried to address some integrative views for the production scheduling problem; namely resources integration, cost elements integration and solution methodologies integration. Representative literature was also covered. The integrative views oriented our attention to the necessity of having a diagnosis methodology assessing the criticality among resources and hence guiding to appropriate formulations and solution methodologies. The development of a criticality evaluation tool is hence an important research avenue.

More research avenues can be suggested. Relevant costs are of special interest when tackling a scheduling problem. This stresses the need for developing cost estimation tools for this purpose. The study of sequences and identification of dominance criteria when solving an integrated scheduling problem is also very important in the understanding and development of solution approaches.

Performance of approaches is most of the time data dependant, so data analysis to guide the choice of approaches is necessary. There has been no effort in exploiting the structural properties of the integrated scheduling problems. Here is an avenue to explore. Development of search strategies and propagation algorithms is also a promising area for enhancing the performance of both operations research and constraint programming techniques.

Our current and future research involves using a number of performing tools such as Tabu search to solve the integrated scheduling problem. Hybridizations with other approaches are being envisaged since tools are sometimes complementary. Objective functions with different cost components are also being used in the different problems under study.

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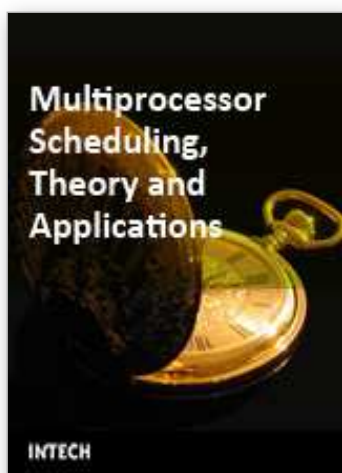
Multiprocessor Scheduling, Theory and Applications

Edited by Eugene Levner

A major goal of the book is to continue a good tradition - to bring together reputable researchers from different countries in order to provide a comprehensive coverage of advanced and modern topics in scheduling not yet reflected by other books. The virtual consortium of the authors has been created by using electronic exchanges; it comprises 50 authors from 18 different countries who have submitted 23 contributions to this collective product. In this sense, the volume can be added to a bookshelf with similar collective publications in scheduling, started by Coffman (1976) and successfully continued by Chretienne et al. (1995), Gutin and Punnen (2002), and Leung (2004). This volume contains four major parts that cover the following directions: the state of the art in theory and algorithms for classical and non-standard scheduling problems; new exact optimization algorithms, approximation algorithms with performance guarantees, heuristics and metaheuristics; novel models and approaches to scheduling; and, last but least, several real-life applications and case studies.

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