Integrating Manufacturing Process Planning with Scheduling via Operation-Based Time-Extended Negotiation Protocols

Izabel Cristina Zattar[a] [1] , João Carlos Espindola Ferreira[a] , João Gabriel Ganacin Granado[a] and Carlos Humberto Barreto de Sousa[a]

[a]Universidade Federal de Santa Catarina, Departamento de Engenharia Mecânica, GRIMA/GRUCON, Florianópolis, SC, Brasil.

Abstract. It is proposed in this paper the on-line adaptation of process plan with alternatives, through the application of an operation-based time-extended negotiation protocol for decision-making about real-time routing of job orders of parts composed of machining operations in a job-shop environment. The protocol is modified from the contract net protocol to cater for the multiple tasks and many-to-many negotiations. The grouping of the machining operations enables reduction of setup times, resulting from the reduction of machines changes. For each part, all feasible routings are considered as alternative process plans, provided the different manufacturing times in each machine are taken into account. The time-extended negotiation period allows the visualization of all of the times involved in the manufacture of each part, including those times that are not considered in systems of this nature, such as the negotiation times among agents. Extensive experiments have been conducted in the system, and the performance measures, including routings, makespan and flow time, are compared with those obtained by the search technique based on the co-evolutionary algorithm.

Keywords. Negotiation protocol, Agent technology, Planning and scheduling

1 Introduction

A large obstacle for the integration between process planning and production scheduling, in dynamic manufacturing environments, is the lack of flexibility for the analysis of alternate resources when allocating the jobs in the shop floor.

According to Shen et al. [4], the integration problem of manufacturing process planning and scheduling becomes even more complex when both process planning and manufacturing scheduling are to be done at the same time. This paper will describe a multiagent system with a heterarchical structure for making decisions

[1] Universidade Federal de Santa Catarina, Departamento de Engenharia Mecânica, GRIMA/GRUCON, Caixa Postal 476, CEP 88040-900, Florianópolis, SC, Brazil; Tel: +55 (48) 3721-9387 extension 212; Fax: +55 (48) 3721-7615; Email: izabel.zattar@gmail.com; http://www.grima.ufsc.br

about the manufacture of parts composed of machining op-erations in a job shop layout, or similar kind of flexible manufacturing environments. The negotiation between the many agents present in the system is based on the grouping of machining operations with an extended period. Each job is announced, subdivided into operations, and later treated as the total sum of groups of machining operations that compose the process plan of the part. In the proposed method, it is also allowed the use of alternative resources for the manufacture of part to increase flexibility in scheduling, but considering their different manufacturing times in each machine. The constraints related to the precedence between the machining operations are taken into account in this model, as well as the machine and fixturing setup times.

2 Related Research

The problem of integrating process planning and production scheduling has been under investigation in the last years, and many different approaches have been applied to accomplish that. More recently many authors have suggested the multiagent systems (MAS) as an adequate approach for solving this problem.

In spite of the advances in this area, it is observed that in many works that use the multiagent approach, a greater emphasis is on production scheduling, both predictive and reactive, while process planning is treated in a static way, i.e. it is determined before the part is released into production. It is also noticed that despite some authors use dynamic process planning in their approaches, there is a recurring problem related to the researches that study the integration of process planning and production scheduling, which is the consideration of the activities that compose the scheduling of an order or a part. In [3], the features that compose each of the parts are treated in an independent way from each other, i.e. a single feature is negotiated at a time between the part and the resources. This kind of treatment may lead to an increase in the setup and queue times, resulting in a longer makespan and flow times. This increase in the manufacturing times results from the many changes machines on which the parts are manufactured, but if the features or operations are grouped based on the setup, this may improve the manufacturing and transport times. These possible gains are investigated in this paper.

3 Characteristics of the Adopted Model

The problem domain in this paper is specific to a job shop environment, or similar kind of flexible manufacturing environments, like open shop, for the production of n parts with m machines. The shop scheduling problem addressed in this paper, there are a given number of jobs on order, with each job having a large number of process plans, which is due to operation, sequencing, and processing flexibilities. Two types of objectives are considered: minimizing makespan and minimizing mean flow time over all the jobs.

3.1 Operation-Based Time-Extended Negotiation Protocol

The operation-based time-extended negotiation protocol is an adaptation of the protocol utilized by Usher [3]. Contrary to the typical duration of a negotiation process used in agent-based systems defined by how long it takes for the messages exchanged between the participating agents to be constructed, sent, and responses received, in the operation-based time-extended negotiation protocol the deadline corresponds to a fixed percentage of the expected time that will be required to setup and process the job on the current resource. According to [3], by considering a definite time interval from the onset of negotiation to the response deadline, each resource can negotiate with multiple part agents simultaneously.

However, the protocol suggested by Usher [3] has as limitations two equally important factors: (a) it does not provide any mechanism for grouping operations that compose a job, and although in that system multiple part agents are coordinated concurrently, each part agent can announce only one single task (or operation) at a time; (b) it considers the setup times independent of operation sequence.

For a better understanding of the setup, the nomenclature used in this paper is presented below. This representation of the variables was adapted from Conway et al. [2], and is used to describe both the sequencing problem and the proposed solution:

- i: index of the jobs to be processed by the shop; $1 \leq i \leq n$;
- j: index of the sequence of operations on a job; $1 \leq j \leq g_i$;
- g_i: the total number of operations on job i;
- $p_{i,m}$: amount of time required for resource m to perform the job i;
- $s_{i,m}$: total setup time of job i on resource m;
- $sp_{i,m}$: total machine setup time of job i on resource m. This value is independent of batch size;
- $sf_{i,m}$: represents the total fixture time of job i on resource m. This value is dependent of batch size.

The proposal time is the sum of all the times considered by a resource agent for the elaboration of a proposal in response to a request made by a part agent. This proposal time indicates the time predicted to start manufacturing the job on the resource. Equations (1) to (4) represent the times that compose the proposal time:

(1) $$\text{Proposal time} = Tq_m + \left(\frac{\sum_{j=1}^{g_i} p_{i,m} + s_{i,m}}{g_i} \right)$$

(2) $$Tq_m = \sum_{i=1}^{n} (q_i + c_i + w_i)$$

(3) $$s_{i,m} = sp_{i,m} + sf_{i,m} * batch\_size$$

(4) Proposal time = $\sum_{i=1}^{n}(q_i + c_i + w_i) + \left(\frac{\sum_{j=1}^{g_i} p_{i,m} + sp_{i,m} + sf_{i,m} * batch\_size}{g_i} \right)$

Where:

- Tq_m: queue time to carry out all manufacturable jobs on a resource. These jobs are already in the resource processing queue, but they have not yet started manufacturing at the instant of negotiation. If there are no jobs in the resource processing queue at the negotiation instant, then Tqm = 0;
- q_i: resource queue time of job i;
- c_i: contract time. These orders have already contracted a resource, but have not yet arrived at the resource processing queue (for instance, they are still being manufactured at a previous resource);
- w_i: waiting time. It is the interval between the sending of the proposal for job execution by a resource agent, and the acceptance of the proposal by the part agent that is negotiating with the resource. If no jobs are in the waiting interval at the negotiation instant, then wi = 0.

For a better understanding of the contract time (c_i), waiting time (w_i), and resource queue time (q_i), which compose Equations 2 and 4, figure 1 presents an example illustrating the exchange of messages between three part agents *i1*, *i2* and *i3*, and three resource agents *R1*, *R2* and *Rn*. Each of the resource agents has an internal counter of the total queue time, *Tq1, Tq2* and *Tqn*, responsible for adding the total queue time (*Tqm*) that will later be used in the proposal.

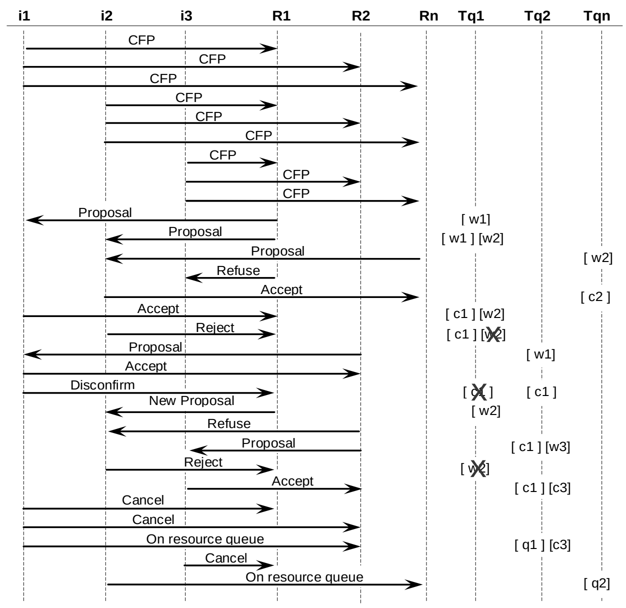

Figure 1. Negotiation between part agents and resource agents

The negotiation starts with part agents *i1, i2* and *i3*, which send a call for proposal (*CFP*), requesting a proposal time to resource agents *R1, R2* and *Rn*. As soon as resource *R1* sends a proposal to *i1*, the counting of the waiting time starts (w_i). This time is calculated in column *Tq1* until resource *R1* receives an "accept" or "reject" by *i1* referring to its proposal. In the case of a positive response ("accept") by i1, the time will not be calculated as waiting time (w_i), and instead it will be considered as contract time (*c1*), remaining that way until job i1 is moved to the resource processing queue. At this instant job *i1* sends to resource *R1* the message informing that it arrived at the resource queue. When resource *R1* receives this message, it considers the time related to i1 as a portion of the resource queue time (*q1*). If the resource proposal is rejected, as it occurs in the negotiation between *i2* and *R1*, where *R1* receives a "reject" of a proposal made to job *i2*, the waiting time (*w2*) is not considered as part of the resource negotiation time, and it is discarded.

3.2 Mechanism to Compare the Proposals

In order to characterize the dynamic scheduling environment, a mechanism that allows the renegotiation between resource agents and part agents even after a "reject" message by the part agent was created. This mechanism is triggered whenever an alteration occurs in the queue of jobs of the resource agent involved in the negotiation. The steps that compose this renegotiation are shown in figure 2.

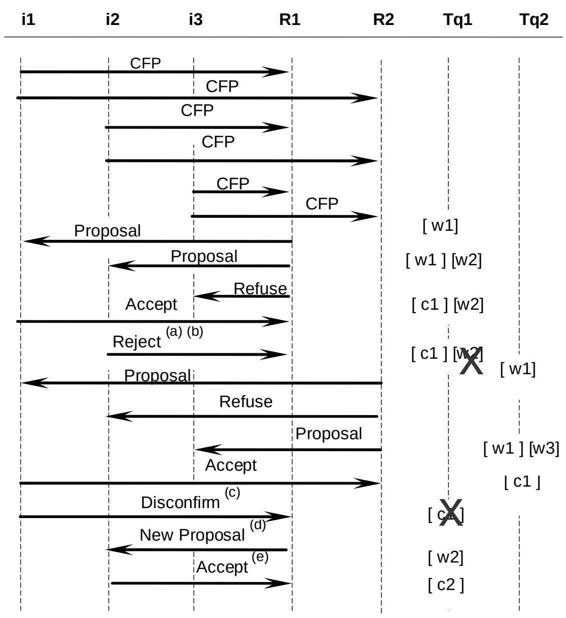

Figure 2. Mechanism to Compare the Proposals

(a) When sending a “reject” proposal, the part agent also needs to send the best proposal that it received until that moment of negotiation, i.e., the proposal that motivated its refusal;
(b) This proposal, which includes the information about the part that originated it, is stored temporarily by the resource agent;
(c) If an alteration occurs in the queue of jobs of the resource agent, such as an order cancellation, this resource will calculate new queue times, updating the proposal time of all of the jobs that are in its physical queue or negotiation queue;
(d) After calculating all the new times, the resource agent will analyze the proposals stored in item (b), comparing them with its new availability. In case the new proposal is better than the stored proposal, the new proposal is sent again to the part agent;
(e) Finally the part agent will analyze this new proposal, verifying if it will accept it or not.

4. Implementation and experiments

In this paper, the performance of the proposed operation-based time-extended negotiation protocol is compared with a symbiotic evolutionary algorithm (SEA) [2]. SEA is a co-evolutionary algorithm that can simultaneously deal with process planning and job shop scheduling in a flexible manufacturing environment. In the hierarchical approach, the process planning is first solved, and then the scheduling problem is considered under the constraint of the solution.

In order to evaluate the performance of operation-based time-extended negotiation protocol, a number of experiments is conducted based on the test-bed problems provided in Kim et. Al [1]. They generated 18 parts with various combinations of flexibility levels. Each job consists of a minimum of 8 and a maximum of 22 operations. They constructed 24 test-bed problems with the 18 jobs. The number of jobs, the number of operations, and the job composition involved in each problem are listed in table 1. The complete set of data for all 24 test-bed problems and 18 parts, including the alternative process plans and the related data, is available in [2] and not repeated here.

Table 1. Test-bed problems

Problem	Number of jobs	Job Number	Problem	Number of jobs	Job Number
1	6	1, 2, 3, 10, 11, 12	13	9	2, 3, 6, 9, 11, 12, 15, 17, 18
2	6	4, 5, 6, 13, 14, 15	14	9	1, 2, 4, 7, 8, 12, 15, 17, 18
3	6	7, 8, 9, 16, 17, 18	15	9	3, 5, 6, 9, 10, 11, 13, 14, 16
4	6	1, 4, 7, 10, 13, 16	16	12	1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15
5	6	2, 5, 8, 11, 14, 17	17	12	4, 5, 6, 7, 8, 9, 13, 14, 15, 16, 17, 18
6	6	3, 6, 9, 12, 15, 18	18	12	1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 16, 17
7	6	1, 4, 8, 12, 15, 17	19	12	2, 3, 5, 6, 8, 9, 11, 12, 14, 15, 17, 18
8	6	2, 6, 7, 10, 14, 18	20	12	1, 2, 4, 6, 7, 8, 10, 12, 14, 15, 17, 18
9	6	3, 5, 9, 11, 13, 16	21	12	2, 3, 5, 6, 7, 9, 10, 11, 13, 14, 16, 18
10	9	1, 2, 3, 5, 6, 10, 11, 12, 15	22	15	2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18
11	9	4, 7, 8, 9, 13, 14, 16, 17, 18	23	15	1, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18
12	9	1, 4, 5, 7, 8, 10, 13, 14, 16	24	18	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18

4.1 Performance Comparison

The performance of the proposed operation-based time-extended negotiation protocol is compared with those three algorithms mentioned above. The experiment for each problem is repeated 10 times for every test-bed problem. The average of this is reported in the tables. The improved rate is computed by the Equation 5.

(5) Improved rate ={mean of SEA approach – mean of proposed protocol/ mean of SEA approach} x 100%.

Table 2 shows the experimental results for mean makespan and flow time, respectively. Since the test-bed proposed by Kim [1] does nor consider the setup times of the operations, it is necessary to carry out two performance comparisons in order to better characterize the nature o this investigation. Column Setup_0 in table 2 refers to the same conditions presented by Kim, i.e., the setup time is not considered. On the other hand, in column Setup_10_10, the total operation time used by Kim was divided in three parts: 80% processing time in the machine (pi,m); 10% machine setup (spi,m); 10% fixturing setup (sfj,m).

Table 2. Comparison of overall Flow time and Makespan

	Makespan								Flow time							
Problem	**SEA**		**Setup_0**		**Improved**	**Setup_10_10**		**Improved**	**SEA**		**Setup_0**		**Improved**	**Setup_10_10**		**Improved**
Set	Mean	s.d	Mean	s.d	**rate (%)**	Mean	s.d	**rate (%)**	Mean	s.d	Mean	s.d	**rate (%)**	Mean	s.d	**rate (%)**
1	437.6	10.9	458.28	10.16	-4.7	432.7	13.2	1.1	318.9	3.7	302.39	5.97	5.2	300.5	5.6	5.8
2	349.7	5.9	334.88	10.60	4.2	331.0	10.1	5.4	287.7	4.7	273.23	2.93	5.0	266.0	3.2	7.5
3	355.2	7.4	329.89	6.15	7.1	318.4	11.7	10.4	304.8	4.3	285.54	5.71	6.3	278.9	5.3	8.5
4	306.2	0.4	301.63	8.83	1.5	297.7	7.5	2.8	251.3	4.8	246.84	1.84	1.8	245.4	4.4	2.4
5	323.7	3.6	306.22	14.81	5.4	320.6	15.6	1.0	280.3	3.2	259.31	5.58	7.5	261.5	6.1	6.7
6	443.8	5.0	455.88	11.35	-2.7	434.5	11.3	2.1	384.7	5.7	353.02	6.55	8.2	343.5	4.8	10.7
7	372.4	1.3	348.54	8.82	6.4	352.8	18.4	5.3	314.1	2.6	297.37	4.21	5.3	291.6	7.6	7.2
8	348.3	5.7	337.68	8.01	3.0	327.3	10.0	6.0	295.2	5.0	281.22	5.13	4.7	278.3	7.1	5.7
9	434.9	9.8	463.47	9.01	-6.6	446.1	4.2	-2.6	298.9	7.0	286.58	2.75	4.1	282.8	7.4	5.4
10	456.5	10.8	467.42	13.43	-2.4	434.6	8.5	4.8	349.2	6.1	313.20	5.07	10.3	309.1	6.9	11.5
11	378.9	5.1	349.38	13.99	7.8	344.7	10.4	9.0	312.9	7.6	288.18	5.47	7.9	285.2	5.1	8.8
12	332.8	3.4	340.01	11.46	-2.2	336.1	29.0	-1.0	279.6	4.7	267.84	4.42	4.2	261.9	6.1	6.3
13	469.0	10.7	456.23	15.21	2.7	436.9	13.2	6.8	387.0	7.1	335.63	5.50	13.3	324.8	4.9	16.1
14	402.4	10.6	367.40	14.83	8.7	369.9	21.2	8.1	346.9	8.5	317.62	5.63	8.4	317.9	4.8	8.3
15	445.2	11.0	471.32	12.71	-5.9	457.3	8.2	-2.7	316.1	6.2	292.66	3.54	7.4	286.7	7.1	9.3
16	478.8	12.0	471.35	34.06	1.6	461.9	27.0	3.5	359.7	4.3	318.60	7.42	11.4	316.8	5.0	11.9
17	448.9	8.7	387.86	28.46	13.6	403.6	36.9	10.1	364.7	4.7	313.46	4.99	14.1	306.2	4.7	16.0
18	389.6	7.5	375.47	9.18	3.6	383.5	23.6	1.6	322.5	6.4	286.44	9.15	11.2	284.8	7.8	11.7
19	508.1	10.0	480.06	18.75	5.5	444.5	14.1	12.5	406.4	4.6	336.41	6.41	17.2	339.4	5.5	16.5
20	453.8	5.2	404.08	14.12	11.0	394.3	18.5	13.1	372.0	5.7	324.78	4.79	12.7	323.1	8.5	13.1
21	483.2	6.8	482.09	17.50	0.2	457.1	13.6	5.4	365.4	8.2	323.23	6.47	11.5	305.2	7.4	16.5
22	548.3	6.9	504.31	36.35	8.0	474.5	12.3	13.5	417.8	5.8	360.68	9.48	13.7	352.2	11.9	15.7
23	507.5	8.3	458.28	33.74	9.7	434.0	21.9	14.5	404.7	5.1	347.28	12.86	14.2	334.4	11.5	17.4
24	602.2	7.1	529.58	27.35	12.1	495.9	26.4	17.6	452.9	7.5	391.77	12.54	13.5	387.4	12.7	14.5
			Mean Improved rate (%) =		3.66	**Mean Improved rate (%) =**		6.18			**Mean Improved rate (%) =**		9.13	**Mean Improved rate (%) =**		10.56

Table 2 reveals that, for several test-bed problems, the proposed operation-based time-extended negotiation protocol provides the best makespan performance among the compared algorithms. The global average obtained is also better than those generated by the other SEA algorithm used in the comparison. The cases in which the results for the makespan are worse than those attained by the SEA algorithm will be investigated in greater detail in the future, since in a preliminary analysis no dominant characteristic was found that could lead to a worse result.

With regard to the flow time for all the given examples, the proposed operation-based time-extended negotiation protocol provides the best performance among the compared algorithms.

5. Conclusion

The system proposed in this paper uses a heterarchical multiagent model that allows the dynamic process planning while reducing makespan and flow time through the reduction of the setup time between the jobs. In order to reach this objective, an operation-based time-extended negotiation protocol was used.

One of the most significant contributions to the efficacy of the proposed operation-based time-extended negotiation protocol is the use of flexible process plans that can be verified step by step during the sequencing and routing of jobs, which allows the resources group the operations that they are capable of manufacturing, reducing the machine setup time. This grouping allows the reduction of both the makespan and the flow time, and this is due to the reduction in the number of machine changes on which the jobs are manufactured. This shows that the simplification of the scheduling problem in a job shop layout through the inclusion of setup times in the total processing time of the machines may result in an incorrect analysis of the problem.

As a future work, an analysis of the influence of the setup times in the reduction of makespan and flow time will be carried out. This analysis will be based on the gradual increase of the contribution of the machine setup time. A mechanism will also be created for the analysis of the effects caused by disturbances on the flow time. At first two types of disturbances will be analyzed: machine failures, and the cancelling of orders that have already been released for manufacture. Also, solutions that minimize the effects of these disturbances will be investigated through the re-dynamic scheduling of the orders.

6 Citations and References

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