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Ranked sequence positional weight heuristic for simultaneous balancing and scheduling jobs in a distributed manufacturing environment

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Abstract

In the current competitive and globalized manufacturing scenario Distributed Manufacturing Environments are increasing, and it turns mandatory to explore improved operational approaches. For enhanced simultaneous balancing and scheduling jobs in a Distributed Manufacturing Environment (DME) a mathematical model of Ranked Sequence Positional Weight (RSPW) is proposed. The model capabilities are analysed through a test problem and the results have demonstrated that the proposed RSPW heuristics mathematical model do perform better than other competitive approaches.

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Keywords: Simultaneous balancing and scheduling; Distributed manufacturing environments; Integer programming; Mathematical model; RSPW; Heuristics.

1. Introduction

Many studies do exist about independent scheduling problems arriving in traditional production units, such as a machine, a shop floor, or a plant, where each type of production units correspond to a management level. Thus, the scheduling problems were investigated independently and separately at each management level. In real-world production, production scheduling decisions occur at different management levels, such as company and plant levels, and are based on correlative dependence and do interplay [1].

Over the past few years much research and study, only to refer some [2, 3, 4], have proven that distributed manufacturing system enables the enterprises to enhance the flexibility and re-configurability for achieving better quality and cost effective manufacturing strategies. Recently emerged extended and networked manufacturing or network based manufacturing paradigm is one such distributed manufacturing system which can support the above mentioned requirements and their functionalities [5].

Production scheduling problems at multiple management levels in a distributed manufacturing environment (DME) have not been simultaneously examined based on a holistic view. Methods in which the use of real-time production data would suffice to make scheduling decisions remain undetermined. A scheduling mechanism that can generate effective scheduling solutions to real-world production scheduling problems in the distributed labor-intensive manufacturing environment needs to be established based on real-time production data.

Most production scheduling problems are non-deterministic polynomial-time hard [6]. Current labour-intensive manufacturing is characterized by short production lead-time, short life-cycles, volatile customer demands, small quantities with frequent product change, and distributed multi-plant production environments. These characteristics inevitably

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increase the complexity of production scheduling problems in the global labour-intensive manufacturing environment.

In this paper we propose a Ranked Sequence Positional Weight (RSPW) heuristic to solve an integer programming mathematical model for balancing and scheduling the jobs in a typical distributed manufacturing environment proposed by [7]. The results will show better performance than other two competitive approaches. The rest of the paper is organized as follows: in section 2 the problem is defined, and section 3 presents the mathematical model and the proposed heuristic to solve him; then, the proposed approach is simulated and the obtained computational results are compared with two other approaches in section 4; finally, in section 5 a conclusion is presented highlighting for the benefits of the RSPW.

2. Simultaneous balancing and scheduling problem in DMEs

Emrul Kays et al. [7] presented a simultaneous balancing and scheduling problem that can happen commonly in the DME, a typical DME comprised by one focal and three local companies. The global decision maker of the focal company was directly involved with the customers by means of receiving the orders and supplying the goods. For satisfying the received customer demand on time, the global decision maker assigns the associated jobs to its geographically distributed local manufacturing facilities and/or companies. In doing so, the global decision makers faced two decision problems i.e. (a) which job to be assigned to which resource and (b) what would be their processing sequences, which could allow the balancing and scheduling problems to be addressed simultaneously. For proper comprehension of this simultaneous balancing and scheduling problem, a typical extended and/or distributed manufacturing environment is illustrated in the following Fig. 1.

In Fig.1 the global decision maker of the focal company is responsible to assign the jobs *j* sequentially to the local company *l* by featuring the local cycle time and/or takt time C. Each of this company *l* is capable to perform any of these jobs *j*. However, to accomplish a job *j*, it needs to undergo two different operations and/or perform two tasks through the sequentially arranged resources. Besides, the focal company has also decided not to allow any form of job preemption after it starts processing through any of the resources in a local company *l*. Therefore, to satisfy the customer demand on time, the global decision maker has to assign the jobs *j* in local company *l* in a manner that the time jobs spent in the resource *r* is reduced. For attaining this objective and solving the simultaneous balancing and scheduling problem, we propose an Integer Programming (IP) model together with a Ranked Sequence Positional Weight (RSPW) heuristic as presented in the following sections.

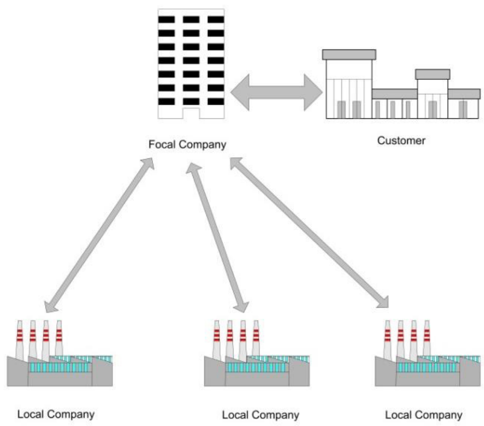

Fig. 1. A typical distributed manufacturing environment.

3. Proposed Model

The notations, indices, and variables that are used in the proposed mathematical model as well as heuristics are given as follows:

Nomenclature

N	total number of tasks
l	number of local companies, l =1, 2,…,m
i	number of tasks, i =1,2,3,…,n
j	number of jobs, j=1,2,3,…,k
r	number of resources, r=1,2,3…,p
a	the number of resource decision variables
s	sequence position of the job j, s=1,2,…,s
t_i	processing time of task i where i ϵ SN
T	a function of processing time
T_l	start time of tasks processing at any local company l
C_{il}	completion time of any task i within each of the local company l
C_{ilrs}	completion time of any task i at factory l in resources r for the sequence position s
$C_{(j,\ s)}$	completion time of job j in sequence position s
$C_{max\ il}$	maximum completion time of task i in local company l
$D_{j,s}$	assignment weights of job j in position s
C	local cycle time and/or takt time
SN	set of all tasks and N∈SN
ST_j	set of tasks that are needed to accomplish for each of the job and $ST_j \subset$ SN
ST_a	set of the numbers of particular decision variables for assigning a task i at sequence position s in a typical resource r
$ST_{b,c}$	set of tasks that precedes a task
ST	set of all jobs for producing an end item
ST_U	set of all unassigned jobs
ST_{el}	set of all eligible Jobs for assigning in local company l
ST_l	set of jobs assign to a local company, l
x_{il}	1 if task i is assigned to local company l; 0 otherwise
R_{iars}	1 if task i is processed in resource r first for sequence position s; 0 otherwise

3.1. Mathematical model

The proposed integer program, as presented below, aids the global decision maker in assigning the jobs to its geographically distributed local manufacturing companies and/or facilities. Moreover, the formulated model also extends its contribution for the focal company by defining the processing orders of the associated task simultaneously. Thus the global decision makers can satisfy their customer demand on time.

$$Maximize \sum_{l=1}^{m}(C - C_{\max il}); \ \forall i \tag{1}$$

Subject to

$$\sum_{l=1}^{m} x_{il} = 1, \forall i \tag{2}$$

$$\sum_{l=1}^{m}\left(\prod_{i \in STj} x_{il}\right) \le 1 \tag{3}$$

$$\sum_{l=1}^{m} l(x_{bl}) - \sum_{l=1}^{m} l(x_{cl}) \le 0; \ (b,c) \in ST_{b,c} \tag{4}$$

$$(C_{clrs} - C_{blrs}) \ge t_{cl}; \ (b,c) \in ST_{b,c} \tag{5}$$

$$C_{ilrs} \le (T_l + C); \forall l \ and \ i \in ST \tag{6}$$

$$C_{ilrs} = T_l + x_{il} * t_{il} * R_{iars}; a \in ST_a \tag{7}$$

$$C_{ilr(s+1)} = T_l + x_{bl} * x_{cl} * (t_{bl} + t_{cl}) * R_{iar(s+1)}; a \in ST_a \tag{8}$$

$$C_{il(r+1)s} = T_j + x_{(i-1)l} * x_{il} * (C_{(i-1)lrs} + t_{il}) * R_{ia(r+1)s}; a \in ST_a \tag{9}$$

$$C_{il(r+1)(s+1)} = T_l + x_{bl} * x_{cl} * (Max(C_{il(r+1)s}, C_{(i-1)lrs}) + t_{il}) * R_{ia(r+1)(s+1)}; a \in ST_a \tag{10}$$

$$C_{clrs} \ge C_{blrs} \tag{11}$$

$$C_{ilrs} > 0 \tag{12}$$

$$C_{\max il} \ge C_{ilrs} \tag{13}$$

Since the objective is to reduce the time jobs spent in the resources r, thereby in this model we attempted to maximize the deviation in between C and Cmax is as presented in Eq. (1). In association with this objective function, the Constraint (2) as presented in the mathematical model ensures that no partial assignment of the job j in local company l allowed. The assignment restrictions i.e. two sequential tasks of any particular job j need to be performed in the same company l, is imposed by the constraint (3). The predecessor-successor relationships of the tasks are respected by Constraint (4) and (5). While the cycle time restriction is expressed by the Constraint (6). The completion time of any task i in the particular sequence position s processed through the resource r in a local company l is defined by the Eq. (7). Whereas the Eqs. (8), (9) and (10) defines the completion time at sequence position s+1 for the resources r and r+1. Meanwhile the constraint (12) ensures the non-zero completion time for each of the task i. Finally, the constraint (13) guarantees that the maximum task completion time will be greater or equal to the completion time of any of the task i. rising.

3.2. Ranked sequence positional weight heuristic

In addition to the mathematical model, in this paper we also propose a Ranked Sequence Positional Weight (RSPW) Heuristic for simultaneous balancing and scheduling the jobs in EMEs/ DMEs. The proposed heuristic starts its iteration by computing the completion time and the sequence positional weight of each of the jobs. The jobs are then assigned to the factories by following the descending order of the computed weights and respecting the precedence as well as the cycle time restrictions. However, during this assignment, all the possible rising of ties in computed weights are either broken by assigning the jobs in ascending manner of their numbers or by following the backward pass procedure. The details of which are described in the following general structure of our proposed heuristics.

Step 0: Create a set of all the unassigned Job STU. At the initial stage STU = ST, which will change for the next consecutive stages.

Step 1: Select a local company l for assigning the job j. Since none of the tasks is assigned in any of the company l, therefore STl = ø.

Step 2: Formulate the set of eligible jobs STel to assign in company l, where STel is a subset of STu. A job j is considered as eligible if j ϵ ST, T(j) ⩽ Clocal, and it follow the precedence relationship. Since, each of the job consists of two different tasks, say x and y, where x precedes y, thereby T(j) =T(x) + T(y).

Step 3: Select the maximum number of job j can be assigned in a local company l and/or the maximum values of sequence position:

$$S = \left[\frac{\sum_{j=1}^{k} Max(T(x), T(y))}{Clocal} \right]^{+}$$

Step 4**:** At this stage, for assigning the jobs j to a local company *l* in sequence position s; the assignment weights (Dj,s) of all eligible jobs are computed as follows:

Dj,s=Clocal-C(j, s)

Here, the completion time of any job j for sequence position s, where each job consists of two tasks x and y (task x precedes y), can be computed as:

C(j, s, x) = T(j, s, x)
C(j, s, y) = T(j, s, x) + T(j, s, y)
C(j+1, s+1, x) = T(j, s, x) + T(j+1, s+1, x)
C(j+1, s+1, y) = C(j, s, x)+Max(T(j, s, y), T(j+1,s,x))+ T(q,s,y)
C(j, s) = C(j, s, y)
C(j, s+1) = C(j+1, s+1, y)

With all this calculated values, the jobs j are assigned to a company l by following the descending orders of estimated weights Dj,s and satisfying the condition C (j,s) ≤ Clocal. However, for the presence of any ties in the computed assignment weights (Dj,s), two different cases are considered:

Case 1: If the ties present in the calculated weights for any particular sequence position s, then it will be broken by maintaining the same order for all the sequence position-s and/or assigning the jobs through the ascending manner of its job number.
Case 2: If the ties are present in the calculated weights between the sequence positions s and s+ 1 for a job j, then it will be broken by following the backward pass i.e. providing precedence in job assignment on the succeeding sequence position s+1.
As, the jobs j are assigned to the company *l* on the basis of their assignment weights and thus STl ≠ ø.

Step 5**:** Compute the makespan (Mi) of company l as follows:

Mi=Max (C (j,s), C (j,s+1))

Step 6: After the assignment of a particular and/or group of the eligible jobs j in the first company l, STel have to be modified as follows:

STe(l+1) = STel- STl

To further the iteration, the following two cases are needed to account:

Case 1: For STe(l+1) ≠ ø (some tasks remain to be assigned) and Clocal- Ms< T (j) repeat from step 2 until STel (mod) = ø.

Case 2: For, STe(l+1) = ø; means there are no remaining tasks to be assigned at the company i thus proceed to the next step.

Step 7: If all the elements of STU have been assigned, thus stop further iterations.

4. Numerical Results

In order to assess the accuracy and validate, the proposed mathematical model the RSPW Heuristic are tested through a case study and/or data set extracted from the research articles [8, 9, 10]. In this adopted case study, to satisfy the customer demand within 12 t. u. (local cycle time), a focal company has decided to assign six individual jobs with their processing sequence to its three local but geographically distributed facilities and/or company. Each of these six jobs needs to undergo two different operations and/or tasks, which can be performed by any of the three associated local companies through their two sequentially arranged resources. These jobs and their relevant tasks processing time are presented in the following Table 1.

Table 1. Processing time for the six jobs and for the associated tasks.

Job, *j*	Job processing time	Tasks, *i*	Tasks processing time
1	6	1; 7	2; 4
2	8	2; 8	5; 3
3	7	3; 9	4; 3
4	10	4; 10	4; 6
5	8	5; 11	6; 2
6	5	6; 12	1; 4

From the context of assessment through this extracted case study and data set, the proposed integer programming model was designed in spread sheet and solved by the What'sBest optimizer on a workstation with an Intel® Core™ i5 processor, 4 GB of RAM memory and Windows 7 64-bit as operating system. Besides, the ranked sequence positional weight heuristic was also implemented to solve this simultaneous balancing and scheduling problem of the extended and/or distributed manufacturing environment. Some of the results i.e. tasks assignment decisions, processing sequence, make spans, obtained through these application of mathematical model and the RSPW heuristic are shown in Table -2. In addition to that, a comparative scenario between our obtained results and the values presented by Santos et al. [10] are also summarized in Table 2.

Table 2. Numerical results obtained.

Local company	Company 1	Company 2	Company 3
Assignment decisions obtained by What'sBest optimizer	T_2, T_6 T_8, T_{12}	T_4,T_5 T_{10},T_{11}	T_1,T_3 T_7,T_9
Assignment decisions obtained by RSPW heuristic	T_6,T_3 T_{12},T_9	T_1, T_2 T_7, T_8	T_4, T_5 T_{10}, T_{11}
Assignment decisions presented by Santos et al. (2014)	T_4,T_6 T_{10}, T_{12}	T_2,T_3 T_8, T_9	T_1,T_5 T_7,T_{11}
Processing sequence obtained by What'sBest optimizer	T_6-T_2 T_{12}-T_8	T_4-T_5 T_{10}-T_{11}	T_1-T_3 T_7-T_9
Processing sequence obtained by RSPW heuristic	T_6-T_3 T_{12}-T_9	T_1- T_2 T_7- T_8	T_4-T_5 T_{10}-T_{11}
Processing sequence presented by Santos et al. (2014)	T_6.T_4 T_{12}-T_{10}	T_2-T_3 T_8-T_9	T_1-T_5 T_7-T_{11}
Makespan obtained by What'sBest optimizer	9 t.u.	12 t.u.	9 t.u.
Makespan obtained by RSPW heuristic	8 t.u.	10 t.u.	12 t.u.
Makespan presented by Santos et al. (2014)	11 t.u.	12 t.u.	10 t.u.

The comparative scenario as presented in Table 2 illustrates different assignment orientations and/or sequences for processing the tasks within three local companies. For instance, the results obtained by What'sBest optimizer advocates to assign job J2 and J6 in a sequence of J6-J2 in company 1, job J4 and J5 in a sequence of J4-J5in company 2, job J1 and J3 in a sequence of J1-J3in company 3. Meanwhile, the results obtained through RSPW heuristics propose to assign the job J6 and J3 in company 1 by following the sequence of J6-J3, Job J1 and J2 in company 2 by following the sequence of J1-J2, job J4 and J5 in company 3 by following the sequence of J4-J5. Whereas, Santos et al. [10] recommended to assign the job J4 and J6 in company 1 as J6 precedes J4, job J2 and J3 in company 2 as J2 precedes J3, job J1 and J5 in company 3 as J1 precedes J5. As illustrated in Table 2, these distinctions in job assignment and sequence decisions leads to different make span for the local companies. However, when the concern is to minimize the time of all six jobs spend in the resources, the proposed NLIP and the RSPW heuristic outperform the results presented by the Santos et al. [10]. Both, What'sBest optimizer and the RSPW heuristic lead to a flow time of 30 t.u., while the 33 t.u. is computed as the flow time from the values presented by the Santos et al. [10]. Besides, the outputs obtained by solving our proposed integer programming model are found in a good agreement with the results attained through the implementation of the RSPW heuristic.

5. Conclusion

In the contemporary world of business, due to the frequent technological advancements and operational changes, the extended and/or distributed manufacturing environments have drawn the significant attention of numerous researches as an alternate robust production paradigm. Irrespective to the kinds of this extended and/or distributed manufacturing environments i.e. service or manufacturing oriented, to satisfy their customer demand on time, the need of appropriate operations management techniques is undeniable. From this context, the simultaneous balancing and scheduling problem of the extended and/or distributed manufacturing environments is considered justifiable. In this paper, to solve this simultaneous balancing and scheduling problem of DMEs, we propose an integer-programming model along with the ranked sequence positional weight heuristic. Both of this model and heuristics not only help the decision makers in assigning the jobs, but also define the optimal processing sequence for the associated tasks. The results obtained through a test problem demonstrate the supremacy of the proposed IP model and the RSPW heuristics over the conventional approaches of balancing and scheduling. In future, both of this IP model and the RSPW heuristics will be extended for large-scale problems and real life implementation.

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