KEDGE BUSINESS SCHOOL
ILS2016
Information Systems, Logistics and Supply Chain
6th International Conference
université de BORDEAUX

Assessment of re-planning solutions: distance measurement between schedules

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Abstract. In order to minimize disturbance impacts on firm management some researches focus on the recovery of initial schedules. This paper presents the method developed by LSIS for assessing scheduling repair solutions taking into account constraints from business rules. This method uses the notion of measure between schedules. First of all, the context of the disturbance management and of the scheduling repair is introduced. Then the principles of the method are presented. Finally a measure of the degree of closeness between the repair solution and the reference schedule is proposed and the method is applied on an industrial case.

Keywords: scheduling, disturbance, repairing, assessment, business rules, distance measurement.

1 Introduction

In a competitive environment, companies try to increase their competitiveness by improving their performance and the organization of their work in order to satisfy customers' requirements in terms of cost, quality and time.

However, in a changing environment, disturbance management needs efficient solutions. That is the reason why LSIS [1] works on re-planning solutions in order to improve disturbance management.

The objective consists in minimizing impacts on human resources and then in limiting changes in the work organization and in the forecast. Consequently, repairing and adapting the schedule is preferred to re-calculating or developing a new one.

The issue of the relevance of repair solutions raises then, in order to stay the closest to the initial solution. In a first stage the comparison between repair solutions was performed mainly using the number of modifications made from the initial schedule, related to pragmatic and business considerations.

The present paper addresses the issue of a more global measurement of the distance between repair solutions and initial schedule.

2 Context and issues

Before launching a project, companies have to make a planning. It consists in setting objectives and determining the use of resources in order to achieve them [2]. Moreover, companies must refine their planning on an operational horizon. This results in a schedule which organises a set of tasks in time, taking into account temporal constraints (time, precedence constraints, etc.) and constraints on the use and the availability of resources required by tasks [3].

Moreover, in a changing environment, it is more and more difficult to respect the reference schedule because of the instability resulting from changes of time limits, availability of resources and other parameters which impact the development of the schedule.

These unexpected changes are called disturbances. They are defined as events triggering situations where the distance between the reference schedule and the achieved schedule is sufficiently significant to modify the schedule [4].

2.1. Issue: how to control disturbances

The objective of the manager consists in minimizing the impacts of the disturbances on the organisation of the project i.e. in limiting changes in work organization and milestones. This assertion implies that the new working organization represented in our case by the new schedule, has to be has close as possible to the initial schedule. Consequently, in the aim to deal with a disturbance, repairing and adapting the schedule is mostly preferred to re-calculating or developing a new schedule.

Repair is defined as a local and limited modification of the initial schedule [5]. So, it consists in a set of operations to implement in order to correct a schedule defined in advance which has been disturbed.

Strategies and repair operations are presented in [6]. Various repair strategies are proposed in order to solve disturbances each one potentially leading to a solution if it succeeds. Thus, the manager can have to select one solution from a set of several solutions. Several industrial areas have been explored from production to building site organization through supply chain planning [6][7][8]. The repair approach can be seen as a metaheuristic exploring in a specific way the space of solutions, looking for the least impacting early feasible solutions.

The first step of this selecting process is to check if the solution is feasible in regards to the operational constraints of the reality: the business rules.

Business rules correspond to constraints of organizations and the way they work on their information systems [9]. Business rules are linked to enterprises' skills. They can be technical or process limitations as well as organizational specifications aimed at obtaining the best management performances.

The second step of the select process is the comparison of the solutions to extract which are the less disturbing, that is to say the closest of the previous situation (ante disturbance).

2.2. Purpose of the work

Various solutions are developed by the implementation of repair operations. So, the decision centre must be aided for classifying these solutions in order to make the manager's choice easier.

The classification of solutions is based on (i) the degree of feasibility which corresponds to the degree of satisfaction for constraints of enterprises' skills and (ii) the optimization of criteria defined according to enterprises' requirements.

The work focuses on the development of a decision aided tool adapted to verify and to validate admissible solutions resulting from repair operations. The objective consists in defining the most optimal and adequate solutions for dispatching resources necessary to tasks and for synchronizing them as long as the solutions cope with the business rules. So the first step will be to verify the business rules and then evaluate and compare the remaining solutions through a metric (distance between schedules). Indeed, the notion of comparing two objects refers to the idea of measuring the distance between the two objects in order to determine their degree of similarity. Searching the optimal repair solution among several solutions can be considered as comparing each repair solutions with the initial solution (which is the pre-established scheduling) and choose the one that optimizes the comparison criterion. In other words this means choosing the repair solution that minimizes the distance separating it from the initial solution.

3. Method for assessing scheduling repair solutions

3.1. Schedule and constraints – business rules

Scheduling consists in defining the beginning and the end of operations or sets of operations in order to show when these operations must be performed for respecting the end date of orders [2].

The complexity of scheduling problems results from the large set of constraints. A constraint shows restrictions on values of decision variables. These constraints can be considered according two points of view: (i) scheduling constraints purely defined and (ii) business rules which are constraints specific to physical processes used by tasks.

Scheduling constraints fall into, in one hand, the category of temporal constraints which require deadlines for precedence or succession constraints and, in other hand, the category of resource constraints which show the availability of resources required by tasks from a quantity or time point of view [3].

Business rules can be defined as assertions which constrain behaviour models of companies [10]. Business rules are declarations on the way to develop enterprises' work according to the organization or the physical process used to perform tasks. Business rules concern guidelines and restrictions about states and processes in companies [11]. From a technical point of view, business rules represent the projection of organizational constraints and way of working on enterprises' decision system [11].

3.2. Proposed method

The method is based on the notion of similarity measure [10] and the notion of distance between two documents used in information retrieval [13] [14].

The idea consists in searching the solution which first satisfies business rules and which is closed to the initial schedule. In other words, it means the solution which causes the least disturbances in scheduling [15].

The proposed method is developed in two steps: the first step consists in the verification and the validation of business rules (see section 3.3) and the second step consists in the measurement of similarity or distance between a repair solution and a reference schedule (see section 4).

Finally, results from the two steps are combined in order to classify feasible solutions according to their distance from initial schedule.

3.3. Verification and validation of business rules

During task scheduling, business rules are extracted from enterprises' skills by business experts belonging to the companies at different decisional levels (from technical to strategic). However, among business rules, some of them may have no influence on the scheduling process.

Indeed, the paper focuses on the set of business rules which interfere in the development of a schedule and also in the selection of the appropriate repair solution. Let us quote rules about task succession, deadlines or conditions about resources using.

In fact, each business rule from this set can be translated into a constraint which affects directly or indirectly the task temporal development and the use of resources by tasks.

Constraints extracted from business rules are translated into logical propositions. A logical proposition is a statement expressing a fact. It can only be true or false [16]. After formalizing business rules, they have to be verified for each repair solution.

A repair solution is feasible or verifies business rules if and only if all the logical propositions translating business rules are true and verified for this solution.

4. Measurement of the degree of closeness between the repair solution and the reference schedule

4.1 Representation of the schedule

Schedule k is represented by:

Matrix M_k which describes temporal resources allocated to tasks T_i^k ($1 \leq i \leq n$) where n is the number of tasks from schedule k.

$$M_k = \begin{pmatrix} t_{d1}^k & t_{d2}^k & \cdots & t_{dn}^k \\ t_{01}^k & t_{02}^k & \cdots & t_{dn}^k \\ t_{f1}^k & t_{f2}^k & \cdots & t_{fn}^k \end{pmatrix}$$

Each column represents vector of temporal resources $T_i^k = \begin{pmatrix} t_{di}^k \\ t_{oi}^k \\ t_{fi}^k \end{pmatrix}$ from task T_i^k impacted by the repair.

t_{di}^k: start date of task i in schedule k.
t_{oi}^k: operating time of task i in schedule k.
t_{fi}^k: end date of task i in schedule k.

Matrix R_k which describes material resources allocated to tasks T_i^k ($1 \leq i \leq n$) where n is the number of tasks from schedule k.

$$R_k = \begin{pmatrix} r_{11}^k & \cdots & r_{1n}^k \\ \vdots & \ddots & \vdots \\ r_{m1}^k & \cdots & r_{mn}^k \end{pmatrix}$$

where r_{ij}^k ($1 \leq j \leq m$) is resource j assigned to task i in schedule k.

Each column represents vector of material resources $\rho_i^k = \begin{pmatrix} r_{1i}^k \\ \vdots \\ r_{mi}^k \end{pmatrix}$ from task T_i^k impacted by the repair.

4.2 Definition of the mathematical distance between two schedules

The calculation of the distance between two schedules implies the calculation of the distance between matrices which represent schedules.
Consequently, the notion of distance between two matrices must be defined because no definition considering constraints from the context described in this paper has been found.
Each matrix is composed of a set of vectors. The distance between two matrices is based on the distance between vectors which compose matrices.

Distance between two matrices

Euclidean distance is selected for defining the distance between two matrices [17]. In fact, this distance is a natural distance from the geometric Euclidean space. The distance between two matrices is defined using Euclidean distance d_v between two vectors.

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \text{ and } B = \begin{pmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{pmatrix}$$

So: $d(A,B) = \sqrt{\sum_{i=1}^{n} d_v(A_i - B_i)^2} = \sqrt{\sum_{i=1}^{n} \left[\sum_{j=1}^{m} (b_{ji} - a_{ji})^2\right]}$

where $d_v(A_i-B_i)$ is the Euclidean distance between vectors A_i and B_i which constitute matrices A and B such as $A_i = \begin{pmatrix} a_{1i} \\ \vdots \\ a_{mi} \end{pmatrix}$ and $B_i = \begin{pmatrix} b_{1i} \\ \vdots \\ b_{mi} \end{pmatrix}$

Measurement of the distance between a solution and the reference schedule

Measure the distance between two schedules is equivalent to measuring the distance between elements representing these schedules.
As shown in section 6.1, a schedule is represented by a temporal matrix and a material matrix. Consequently, measuring the distance between two schedules means measuring the distance between temporal matrices and the distance between material matrices in order to deduce the overall distance between the two schedules.

Temporal distance between a solution and the reference schedule (time difference)

Solving disturbances in order to repair schedules impact temporal resources. The solution which minimises disturbance impact on the beginning and the end of operations and on operating times is selected. In fact, distances between matrices which represent repair solutions proposed to solve temporal difference and the matrix of the reference schedule are calculated in order to assess these solutions.

Given two matrices M_r and M_k which represent respectively the reference schedule and a repair solution, the distance between them is defined using Euclidean distance:

$$d(M_r, M_k) = \sqrt{\sum_{i=1}^{n} d(\tau_i^r - \tau_i^k)^2}$$

Where: $T_i^k = \begin{pmatrix} t_{di}^k \\ t_{oi}^k \\ t_{fi}^k \end{pmatrix}$ is the vector of temporal resources of task i in schedule k.

Distance between material resources used by a solution comparing with the reference schedule (impact on resources)

In the same way as repair solutions are compared from a temporal point of view, distances between the resources matrices of each solution and of initial schedule are compared. In the same manner, the Euclidean distance is used to calculate distance between matrices.

Given two resource matrices R_r and R_k representing the reference schedule and the repair solution, the distance between them is defined as follows:

$$d(R_k, R_r) = \sqrt{\sum_{i=1}^{n} d(\rho_i^r - \rho_i^k)^2}$$

Where: $\rho_i^k = \begin{pmatrix} r_{1i}^k \\ \vdots \\ r_{mi}^k \end{pmatrix}$ is the vector of material resources for task i in schedule k.

Distance Time/ Resources between a solution and the reference schedule

Once the two distances (temporal difference and impact on resources) calculated for each repair solution, each solution S can be represented in a coordinate system by its distance vector (E, I) where E is the temporal difference and I is the impact on resources (figure 1).

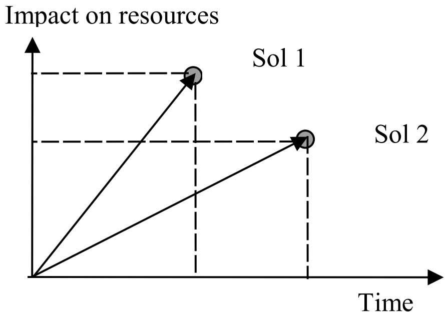

Figure 1: Distance vectors (time difference, impact on resources) representing repair solutions

In a bi-dimensional Euclidean coordinate system, each solution is represented by a bi-dimension vector (E, I) in order to show it and to assist in its assessment. However, it is difficult to assess solutions through vectors from their components. In fact, the overall distance of each solution from initial schedule must be calculated from its vector of distance. A way to do that consists in calculating the vector norm. Several norms are presented in the literature. Euclidean norm is selected to be implemented in the issue dealt in the paper because it is a natural norm and the most widely used.

The assessment of solutions Si is based on the resulting distance from initial schedule R using the Euclidean norm of the vector (temporal difference, impact on resources) defined as follows:

$$d(S_i, R) = \sqrt{E_i^2 + I_i^2}$$

where E_i is the time difference for S_i and I_i is the impact of the recovery on resources of S_i .

4.3. Classification of repair solutions

Solutions can be classified according to distances from the initial schedule. The less the distance is, the greater the similarity degree between the solution and the initial schedule and the most appropriate the solution are.
In the case where the distance from the initial schedule of two solutions represented by different vectors are the same, the manager will have a difficult choice to make between these two solutions;
In the case where the decision-maker has a preference for a solution (for example, he prefers changing a machine used to perform a task rather than shifting the beginning of this task), he can favour the solution which satisfies his preference over the other solutions.
Otherwise, a method for differentiating two solutions characterized by the same distance consists in weighting components E and I from solution vectors. Weighting factors are defined by the decision maker according to his appraisal of the significance of temporal difference and impact on material resources and according to his experience.

5. Implementation on an industrial case

Company PLASTIX is specialised in the production of profiles and supplies in plastic for the building industry (baseboards, spouts, door frames, mouldings…)
The plant is mainly composed of:
- An injection moulding workshop for plastic;
- An assembly and packaging workshop.

The company offers a schedule of actual injection moulding workshop for 12 days which corresponds to the average horizon of production for the workshop. It affects 6 injection presses. Three of them are mainly specialized in four raw materials from the family of group G1 (ABS, PS, PP and PE); three others are specialized in two raw materials from the family of group G2 (PA and PC).
In order to solve disturbances which can occur in the initial schedule, the company wants to develop a decision aided system for reacting to disturbances and for minimizing their spreading. This system will propose repair solutions for scheduling and make the selection of the appropriate solution easier.
In order to implement the method for assessing repair solutions on the schedule from injection moulding workshop, let us consider the example of a disturbance occurrence. Five repair solutions have been developed according to five different repair strategies to solve this disturbance.
Applying repair operations change the sequence, dates, and resources used by the tasks impacted by the disturbance, in relation to the initial scheduling. The solutions are characterized by the task impacted by the repair operations (tasks shifted and task having their time margin changed by the repair operations), as seen in table 1.

Table 1: Tasks impacted by the repair solutions.

Repair Solutions	Task preceding the shifted task	Time Margin	Task shifted by a repair operation	Time Margin	Task following the shifted task
Solution 1	063312	30min	248242	30min	849162
Solution 2	849162	30min	063312	30min	248242
Solution 3	063312	30min	248242	30min	849162
Solution 4	250011	40min	248242		
	530357	3Days	849162		
Solution 5	243032	30min	849162		

But these changes can be not in phase with the business rules. So the first step of the method consists in verifying and assessing business rules. To do that, Plastix's constraints were classified in two categories: scheduling constraints and constraints resulting from business rules.
Then, they are formalized in logical propositions as, for example:
- 16 minutes necessary for changing raw material from group G1 to group G1 or for group G2 to group G2, masked by the setting-up time

=> Whatever two successive tasks T_i and T_j performed on the same machine and both belonging to group G1 or group G2, so: (T_j start date – T_i end date) >= 16 mn

Then, the five solutions verify the logical propositions representing business rules. Propositions are true for all the solutions. Consequently, the five solutions are admissible and verify business rules.

The second step of the method aims at measuring the distance between repair solutions and reference schedule. For our case, the set of tasks impacted by strategies 1, 2, 3, 4, and 5 is W = {063312, 248242, 250052, 849162}. The initial temporal vectors of the tasks of set W are shown in the table 2 below.

Table 2: Temporal vectors of impacted tasks

Tasks	063312	248242	250052	849162
Start date	156	247	249	239
Operation time	83	5	9	8
Finish date	239	252	258	247

The matrix representing the reference schedule is then: $M_0 = \begin{pmatrix} 156 & 247 & 249 & 239 \\ 83 & 5 & 9 & 8 \\ 239 & 252 & 258 & 247 \end{pmatrix}$

And the matrix for repair solution 1 is: $M_1 = \begin{pmatrix} 156 & 239 & 249 & 244 \\ 83 & 5 & 9 & 8 \\ 239 & 244 & 258 & 252 \end{pmatrix}$

Similarly, and maintaining the order of temporal vectors of the tasks of set W, we can represent the schedules resulting from the application of the mentioned repair strategies in five solution matrix, and then calculate, as shown in section 6.2, the distances between the solutions and the reference schedule, as for solution 1 :

$$d(M_0, M_1) = \sqrt{(247-239)^2 + (252-244)^2 + (244-239)^2 + (252-247)^2} = 13{,}34$$

At last, solutions are classified according to the distance in the following histogram (figure 2).

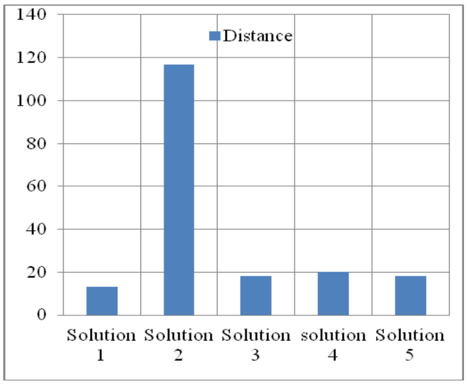

Figure 2: distances between repair solutions and reference schedule

Solution 2 is the most distant from the reference schedule compared to other solutions. Consequently, this is the worst solution. Solution 1 is the closest to the reference schedule. Consequently, it is proposed as the best solution.

Solutions 3 and 4 show the same distance and are ranked behind solution 1; they are admissible and they can be used in the case solution 1 does not verify a criterion or a decision maker’s preference. In this case, the decision maker must be able to tell the difference between these two solutions. He can weight temporal and material distances in order to recalculate the overall distance of each solution

6. Conclusion and prospects

The objective of the work consists in supporting decision makers for the selection of the most appropriate repair solutions among several developed repair solutions in order to solve disturbance occurrences in a schedule.

Repair operations make possible the system to recover normal functioning while minimising changes in pre-made schedules.

When several repair solutions are developed, the decision maker faces the dilemma of selecting the most appropriate solution. The decision system shows the results from admissible solution classification using the business rules verification and the comparison of repair solutions.

The proposed assessment method shows limitations in the case of major projects composed of a large number of tasks which can be affected by several disturbances. In this case, the calculation of the distance between two schedules will be complex to perform because of the large size of their matrices.

Perspectives for this work are identified. First of all, it would be interesting to enhance the method and to adapt it for all the kinds of schedules. To do that, it would be appropriate to study the contribution of other sorts of distances and similarity metrics on the measure of degree of closeness. It would be necessary to characterize conditions of use of each distance.

Then, another perspective concerns the issue of two solutions with the same degree of closeness. How does the decision maker define weighting factors used in the calculation of the weighted distance in order to select the most appropriate solution?

Finally, if some tasks or resources have a higher significance level, a weighting would be allocated to distances concerning their vectors. So, how to define the weighting factors?

References

1 A. Cauvin, A. Ferrarini, E. Tranvouez, "Disruption management in distributed enterprises: A multiagent modelling and simulation of cooperative recovery behaviors," International Journal of Production Economics, vol. 122, pp. 429-439, (2009)
2 J.H. Blackstone, J.F. Cox, Dictionnaire de l'APICS, 11th ed., (2005)
3 P. Esquirol, P. Lopez , "Ordonnancement de la production". Paris: Hermès Science, (2001)
4 A. Cauvin, S. Fournier, A. Ferrarini, "Disruption Management in Distributed Organizations: A Cooperative Repair Approach For Reactive Planning And Scheduling," Progress in Economics Research, vol. volume 23, (2011)
5 M. Zweben, E. Davis, B. Daun, & Deale, Scheduling and Rescheduling with Iterative Repair: IEEE Transactions on Systems Man and Cybernetics, vol. vol. 23(6), (1993).
6 S. Fournier, A. Ferrarini, A. Cauvin, "A MultiAgent Approach for Reactive Planning and Scheduling in Distributed Organization" (2011)
7 S. Fournier – A. Ferrarini, "A MultiAgent scheduling repair method for disruption management in complex socio-technical organizations" , in : Springer Berlin / Heidelberg, Trends in Practical Applications of Agents and Multiagent Systems, Demazeau, Yves and Dignum, Frank and Corchado, Juan and Bajo, Javier and Corchuelo, Rafael and Corchado, Emilio and Fernández-Riverola, Florentino and Julián, Vicente and Pawlewski, Pawel and Campbell, Andrew, Vol. 71, pp. 191-199, Advances in Soft Computing, avr 2010
8 A. Ferrarini – S. Fournier – E. Tranvouez – A. Cauvin, "Decision aid using multiagent models and simulation - Disruption Management in Building Site organization" , 20th International Conference on Production Research (ICPR20), 2-6 August 2009, Shanghai, China, 2009
9 P. Kardasisa, P. Loucopoulos, "Expressing and organising business rules," (2003).
10 I. Sack, A. Bhate J. Morabito, "Organisation Modelling, Innovative Architectures for the 21st Century," PrenticeHall, (2001)
11 H. Herbst, "Business Rule Oriented Conceptual Modelling," Physica-Verlag, PhD Thesis, (1997)
12 K.M. Saiful Islam B.R. Sarker, "Relative performances of similarity and dissimilarity measures," Computers & Industrial Engineering, pp. 769–807, April, (2000)
13 J. Zhang, E.M. Rasmussen, "Developing a new similarity measure from two different perspectives," Information Processing and Management, pp. 279-294, may, (2000)
14 A. Huang, "Similarity measures for text document clustering," (2008)
15 S. Laqrichi, "Elaboration et opérationnalisation d'une méthode d'évaluation des solutions de réparation de planning ", M.Sc. Université Paul Cézanne, June, (2012)
16 R. Chill, Logique et théorie des ensembles, (2009)
17 C. Joulain, L. Lesieur, Mathématiques M.P.C. Tome 1 algèbre, géométrie et mécanique : Armand Colin, (1965)