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The role of complexity and flexibility of the instance in the joint solution approach

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Abstract Many pieces of research address the development of new algorithms and new solution techniques for decision-making; however, most of them do not consider the characteristics of instance in their analysis, such as the complexity and flexibility of the instance. Building a complex model, such as a joint model, requires a huge amount of time and effort while the resulting solution of such joint models may or may not be the best solution for all the actors involved in the process. Therefore, it is important to make an in-depth analysis of the instance before investing the time and effort to build a joint model. In this regard, this paper provides an instance evaluation procedure to help decision-makers decide whether to use joint decision or not for a particular instance.

Keywords: Joint decision, Flexibility, MILP, Flexibility, Complexity

1 Introduction

The traditional decision-making process is usually sequential where the best decision is taken for the first stage of the process and then this output of the first stage is used as a basis for the next stage decisions and so on. However, by using a se-

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quential decision-making process it is difficult to reach an overall optimal solution as the final decisions completely depend on the first-stage decision. To overcome this limitation a joint decision approach offers a great opportunity to reach an overall optimal solution by enlarging the search space. Joint decision-making can have many implications since, besides the intrinsic cost and time to develop the joint model, it may involve a possible change in the organizations in order to allow different actors to share information and to persuade global goals instead of local goals. This requires a close collaboration and coordination among the different actors involved in the overall process. Interestingly, many operations management researchers assume that “integration is a must” and that cross-functional coordination and integration are necessary (Ketokivi, 2006). However, in later research, Turkulainen et al. (2012) argued that the benefits of integration and cross-functional coordination are context-dependent and sometimes disaggregation is beneficial.

Joint decisions usually result in a paradox since the different actors may not achieve the optimal solution for their sub-operations in order to achieve an overall optimal solution. Therefore, a joint decision-making process could be attractive for some circumstances and unappealing in other situations. Considering this paradoxical nature of joint decisions, this research attempts to explore “When is it advisable to use a joint decision-making process and when is it better not to use it? The contribution of this paper is to create an “instance evaluation procedure” based on the complexity and flexibility of the instance to help the decision-makers to decide before investing their time and effort in the preparation of a joint decision model. To this end, the authors argue that it is highly important to consider instance characteristics before setting out on a joint decision model.

1.1 Characteristics of the Instance

The instance is the complete set of data that defines the problem space e.g. in the case of a scheduling problem the number of days, workers, job shops, production lines, units to produce and so on. One of the most important characteristics of an instance is the size of the problem, which is determined by the number of continuous and binary variables that represent all the relationships among variables and parameters. The problem size is considered as a major contributor to the complexity of the instance. However, there are many other factors that need to be considered when analyzing the instance complexity. The complexity and flexibility of the instance plays a crucial role in the decision-making process. For dynamical systems theory the complexity measures are usually computational complexities that are a measure of the interactions (Adami, 2002). Similarly, Heylighen (2008) highlighted that a fundamental part of any complex system is the connected parts via interactions. These parts can be distinct and/or connected as well as autonomous and/or to some degree mutually dependent. This interdependence can create conflicting goals since the improvement of one part could lead to the decrement of the other part. Therefore, just considering the total number of variables present in a problem space as the only parameter/measure of complexity is not the right approach. Many other factors need be considered when analyzing the complexity of an instance. An important work in this regard is by Vanhoucke and Maenhout (2009) where they characterize the Nurse scheduling problem. In their work, they highlight four factors to analyze the complexity of the indicators: a) problem size, b) the preference distribution measures, c) the coverage distribution measures, and d) the time related constraints.

Similarly, flexibility of an instance is another key characteristic that needs to be considered when analyzing a joint decision. Flexibility is “the ability to change or react with little penalty in time, effort, cost, or performance” (Upton, 1994). Thus, a flexible instance of workers means the extent to which the employees can perform different tasks. In this research, we propose considering three new factors while analyzing the instance characteristics. These factors include preference distribution, coverage distribution and cost dispersion.

2. Factors for instance analysis

In this section we propose and define three indices that need to be considered when analysing an instance for a joint decision. These factors are discussed briefly.

2.1 Preference distribution (PD)

The preference distribution measures the dispersion among the needs or requirements of resources by the different entities over the scheduling horizon. If all the requirements are similar the preference of distribution will be low, on the other hand if all the requirements are different this index will be high. It can be measured using equation 1. Where $Entity_i$ is the requirement of resources of the entity.

$$Coverage = \frac{\sqrt{\frac{\sum_{i=1}^{N}(Entity_i - \overline{Entity})^2}{NumberOfEntities}}}{\overline{Entity}} \tag{1}$$

2.2 Extra coverage constrainedness (ECC) Rigidity / Flexibility

The coverage requirements are expressed by the average of the extra capacity (availability) of all machines (resources). When this number is close to 0, we could say that it is a rigid instance that there is no extra resource; when it is close to 1 its means that it is a flexible instance meaning we have some extra resources. This factor can be measured with the help of equation 2.

$$Req = \frac{\sum_{Machine}\left(1-\frac{requirement_{machine}}{capacity_{machine}}\right)}{number\ of\ resources} \tag{2}$$

2.3 Cost dispersion (CD)

The cost dispersion is a measure that is used to quantify the variation of cost among the different areas, in which the decision will be made together. We will refer to the total cost of each part, for example in the case of the inventory it will be the total cost of the inventory not the cost of each unit of inventory. It can be measured using equation 3.

$$CostDispertion = \frac{\sqrt{\frac{\sum_{i=1}^{N}(Cost_i-\overline{Cost})^2}{NumberOfCosts}}}{\overline{Cost}} \tag{3}$$

In the next section, these factors are studied using 2 case studies where different combinations of the preference distribution, extra coverage constrainedness and cost dispersion are tested. The size of the instance is constant and the amount of resources available helps to characterize the instance. The three indexes vary between low (close to 0) and high (close to 1).

3 Case studies and Results

The computational experience was performed in a Windows-PC with an Intel Core 7, 8 GB of RAM, running Windows 7, with the AIMMS 3.14 mathematical modeler and Gurobi 6.0. A maximum stop criterion of 3600 sec was set for all instances.

3.1 Case study 1

In a car assembly line, the production sequence has to be decided for the planning period. Each workstation could deal with a production rate, which means that a workstation could install X high trim components each Y cars. In the event that the number of high trim components is higher, an extra utility worker has to come to help, with a penalty cost. Each station installs a different type of component that needs to be next to the assembly line before it is needed. The transportation vehicles carry these components from the warehouse to the workstations where it is assumed that all the components exist. Each model has a set of characteristics, such as engine, rims, tires, steering, etc. These components could have different trims (Low or High). All the models are different from the other models in at least one type of component. The components required at each workstation are delivered as a kit. The model was implemented using mixed integer linear programming. A detailed description can be found in (Pulido et al. 2014a). There are 3 main decisions that have to be taken and are usually taken sequentially.

1. The production sequence that minimizes the use of extra utility workers.
2. The distribution cost of components that minimizes transportation cost.
3. The inventory level that minimizes the inventory cost.

The first index will be calculated as the deviation of the number of high trim elements that each car requires, and the average entity will be the one for which the assembly line was designed. For the second index, the machines will be the workstation and transportation vehicle. The requirement of workstations of the car assembly line will be the requirement of each car model for this workstation, while between the production ratios and for the transportation vehicles, the requirement will be the demand for the use of a vehicle, and its capacity will be the transportation capacity.

The results of the experimentation are presented in Table 1. Where the first column of the instance defines the instance with respect to three indexes, and the left part of the table is the result of the traditional sequential approach while in the right part is the result of the joint approach. Promising results appear when the preference distribution is high, and there is diversity among the tasks that have to be done. Also when there is extra coverage of resources since there is flexibility of the allocation. And finally when there is diversity of the cost there are promising results, especially when the biggest cost contributor is the last of the sequential model.

Table 1 Result of Case Study 1.

PD,ECC,CD	Sch	Transp	Invent	SeqD	Sch	Transp	Invent	JointD	Savings
L,L,L	594	1432	928	2954	638	1424	796	2858	3%

L,L,H	594	716	9283	10593	638	715	7921	9274	14%
L,H,L	0	1439	902	2341	0	1426	813	2239	5%
L,H,H	0	720	9023	9743	22	716	7979	8717	12%
H,L,L	308	1435	944	2687	308	1434	834	2576	4%
H,L,H	308	718	9436	10462	396	714	8124	9234	13%
H,H,L	0	1436	947	2383	0	1424	795	2219	7%
H,H,H	0	718	9469	10187	0	712	7952	8664	18%

3.2 Case study 2

The teaching hospital plays a key role in the health care system. Inside the hospital, the main part of this structure is the operating rooms, since the majority of the patients go through the operating room

The scheduling of the surgeries is important since the vacant time of the operating room, the idle time of a surgeon, and the extra time cost of the operating room impact directly on how the hospital functions. A detailed explanation of the model can be found in (Pulido et al. 2014b). There are 2 main decisions that have to be taken and are usually taken sequentially.

1. The doctor who perform the surgery that minimizes the extra time. Each surgeon has a different expertise and could perform a surgery faster or slower.
2. The operating room schedule that minimizes the vacant time of the surgeons and idle operating rooms.

The first index will be calculated as the deviation of the length of the surgery against the average surgery duration. In order to calculate the second index the machine will be the surgeons and operating rooms. The requirement of surgeons will be the total length of the duration of the surgeries that could be performed by a surgeon between the shift length (capacity) while the requirement of the operating room will be the total length of surgeries that can be performed in this operating room between the shift lengths.

Table 2 presents the results. First the indexes used, then the overtime, vacant OR time and surgeon waiting time cost for the sequential decision and the same three cost for the joint decision, and the savings. The Joint Decision is advisable with promising results when the preference dispersion is high, because when it is low the results are negligible. The role of the ECC is minor, since it plays a complicated role, as there is a penalty for the extra resources (vacant time cost). The dispersion of the cost is also important, especially when the cost of vacant time is high.

Table 2 Result of Case Study 2.

PD,ECC,CD	OverT	VacT	WaitT	SeqD	OverT	VacT	WaitT	JointD	Savings
L,L,L	1307	885	362	2554	1387	885	210	2482	3%
L,L,H	980	885	620	2485	1040	905	360	2305	8%
L,H,L	0	1020	350	1370	13	885	210	1108	24%
L,H,H	0	1020	600	1620	0	1135	120	1255	29%
H,L,L	1027	1545	58	2630	1307	1065	58	2430	8%
H,L,H	770	1545	100	2415	980	1065	100	2145	13%
H,H,L	40	990	362	1392	40	1065	58	1163	20%
H,H,H	0	1050	540	1590	0	1035	100	1135	40%

4 Prescriptive framework

A prescriptive framework is developed based on results, and acquired experience is presented. With a more detailed analysis of the input data, we can assess the preference distribution of the instance, the extra coverage (flexibility/ rigidity) of instance, and the homogeneity of the cost. If the results of this preprocessing of the data are promising, we can decide to take the next step and start to build a joint model.

When the preference distribution is low, which means similar products or tasks need to be produced/performed, the benefits of the Joint Decision decrease. On the other hand, if we have bigger diversity the results could be promising.

The extra coverage constrainedness plays a key role and will depend on whether there is a penalty or not for having extra resources. However, if there is no extra coverage the possible savings will decrease.

The major influence that we found is cost dispersion since when it is low the results are not so promising, but when there is a high dispersion then it is necessary know the position of the most expensive cost as this plays a key role. When the highest cost is the final decision, the possible savings increase considerably.

However, for choosing the right type of model, it is important to take into consideration the number of actors or the size of the problem since this will determine if we use exact or non-exact methods. The goal ambiguity, frequency of decision and uncertainty should be taken into consideration in advance in order to decide on exact or non-exact methods.

For the reason mentioned previously, we suggest analyzing the likelihood of savings based on the preference of distribution, coverage of the instance and homogeneity of cost. Figure 1 shows the proposed evaluation process/ procedure.

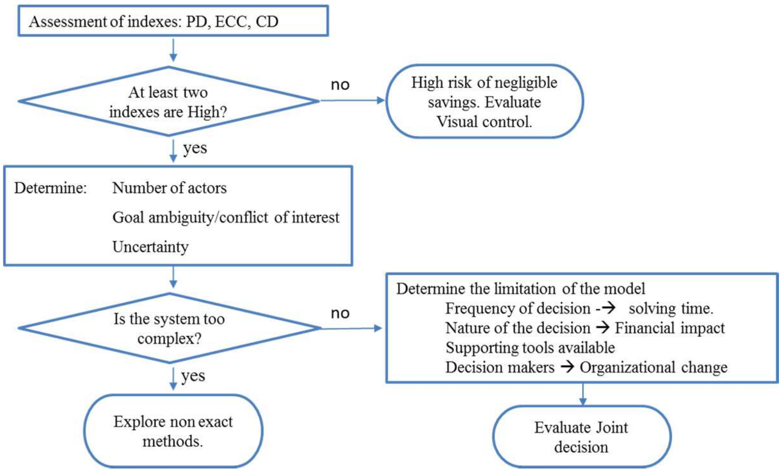

Fig 1. Instance Evaluation process

5. Conclusion

The major benefit of a joint decision is the possible cost savings, thanks to the better utilization of key resources. The decrease in the cost is accompanied by an improvement in the key performance indicator such as the use of resources or the decrease in overtime. As expected, the use of a joint model increases the size of the model, the complexity and the solving time. When the computational time is high other non-exact solution methods should be evaluated with the risk of a decrease in saving for non-achievement of the global optimum.

The range of possible savings for the same problems using a joint model depends on the data is quite large, but the bottom line is close to zero. Then, before deciding the type of model, we suggest pre-evaluating the instance as in some cases the implementation cost can be higher than the savings. Therefore, in some cases it is better to use the traditional sequential approach since the preparation of a complex model does not guarantee enough savings to justify the development of the joint model. Hence, this research concludes that any possible savings of a joint decision are case-dependent and every case should be evaluated before investing time and effort in a joint decision approach. The case/instance should be evaluated from its complexity and flexibility perspective.

As a further work we intend to test the proposed framework using more case studies, which can be generalized to other areas to try to help other researchers and practitioners to decide when or not it is better to use a joint decision.

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