CHARACTERIZATION AND MODELLING OF FLEXIBLE RESOURCES ALLOCATION ON INDUSTRIAL ACTIVITIES

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Abstract

Scheduling of industrial activities requires to solve two different types of problems : the first one consists in respecting precedence constraints between tasks – these constraints being imposed by the logic of realization. The second one aims at allocating resources on these tasks. Scheduling is traditionally performed with a double assumption : each task is supposed to be of a given duration, and each resource (or group of resources) is characterized by a given availability – most often, this availability is constant with time ; in some cases, the scheduler can take into account some extra-hours for some resources.

This problem is somewhat different when two adjustments are proceeded on this model. Instead of being characterized by a fixed duration, tasks can be seen as a given amount of work to perform : therefore, the duration of a task will rather be the result of a choice made on the resource(s) allocated to do this work, taking into account their number as well as their efficiency. Possibly, this duration will be restricted within limits expressing economic constraints on time span (upper limit), or the decrease of workforce efficiency with increasing number of people sharing the same space (lower limit).

A second adjustment of the previous model results from the flexibility of human resources – this flexibility having two separate origins. Part of this flexibility is due to the work time modulation – a given worker is due to work a fixed number of yearly working hours, and the distribution of these hours within this period is free, provided some daily, weekly, and monthly quotas are not exceeded. Another flexibility tool comes from the ability of some workers to perform two (or more) types of jobs related to two or more skills –taking into account, if needed, different efficiencies in each of these skills.

The projected article aims at developing such a model, and at presenting a resolution methodology ; this methodology should include evaluation of performances for the solutions provided : from a point of view that would be economic (in terms of cost and makespan for a whole industrial activity) as well as operational (in terms of evaluating how they preserve or damage the future flexibility of the resource pool).

Introduction

The improvement of resources allocation systems on industrial activities is a problem of growing importance and complexity ; firms are looking for more and more flexibility to face increasing uncertainty in customers' needs [1,2]. Since technical resources (machines and tools) are rather predictable in their behaviour, a growth in the flexibility of a company requires a deep change from the human factor.

While the last century's Taylorian logic would coordinate the activities of people associated to work stations [3], our approach aims at a two-steps resource allocation : the very definition of an industrial task, whatever it is, relies on a description of the competence that is needed to perform it, and on the evaluation of the total amount of efforts it requires. Then, the allocation can be completed by the determination of the resource(s) that can adequately provide these efforts with that competence.

From that point of view, a source of flexibility can be found from multi - skilled actors [4], bringing the opportunity to face a greater number of solutions to a given problem of resource allocation on a series of tasks. These solutions may then be evaluated from an economic point of view, via the appreciation, for each actor involved, of the way he masters or not a given skill and the impact it can have on his workload. The skills mastered by an operator can be formulated as a list of knowledge and know-how which operation allow to perform a task. More generally, the notion of skill may have two significations: the ability for an actor to achieve a specific activity in the company, and the knowledge and aptitude needed to achieve this task with efficiency [5, 6, 7]. The present work introduces a methodology of resource allocation based on the flexibility induced by multi-skilled actors.

In this communication, we will describe the importance of an actor's competence and its influence on the workload scheduled for the achievement of different activities. And we will illustrate that this competence is not a fixed characteristic, but that it may evolve due to other parameters.

Definitions

In the following, we will deal with ***industrial activities***, not regarding whether they are unique and original or pre-defined and repetitive : therefore, these industrial activities may represent a project as well as a production program. In both cases, they may be divided in ***tasks***. The human resources will be called ***actors*** – these actors can then be project resources as well as production operators. Multi – competence will be referred to as ***polyvalence***, and ***efficiency*** will describe the way an actor masters a given skill. We will not consider material resources in the scope of this work.

The following notations will be used :

a	Actor index
i	Tasks index
k	Competence index
$d_{a,i}$	(*days*), Duration, for actor *a* to complete task *i*
D^o_i	(*days*), Standard duration, for task *i*
$E_{i,k}$	(-), Workforce, of competence *k* on task *i*
Q_k	(-), Global disponibility, of competence *k* in the company
$W_{i,k}$	Workload, for competence *k* on task *i*
α	(*Hours*), duration of standard working day
$\theta_{a,k}$	(-), Efficiency, for actor *a* in competence *k*

Efficiency and duration

A polyvalent actor provides the company with more than one skill which may result on his allocation to many different tasks. The main advantage this flexibility lever offers is that company, from a fixed workforce available, may have at its disposal a variable workload on a given competence – provided all competences are not over – required at the same moment.

For a given actor, each skill is characterized by a parameter called efficiency : thus, the efficiency $\theta_{a,k}$ of the actor *a* on the competence *k* is a non – dimensional value ; let us state that $\theta_{a,k} \in [0 , 1]$. A value of 1 indicates a nominal efficiency of the actor, in his first competence (original job) ; values lower than 1 indicates efficiencies in additional competences he would have acquired – or he would not have practised for some time. We also state that every actor in the company has at least one “nominal” competence (ie, his efficiency in this competence is1).

In that case, the planner may report some overloads on available actors, even if their efficiencies on the needed competences are not optimal. This may avoid paying for extra hours or outsourcing jobs [8, 9].

The evaluation of efficiency is directly linked to the duration needed to perform a given task – thus, an actor with a non – nominal efficiency will need more time to perform a job than one who would have, on the same competence, an efficiency of 1. For instance, a given task (*i*) requires a competence (*k*) and has a standard scheduled duration D^o_i – which means that this duration corresponds to the makespan needed for an actor of nominal efficiency in the competence (*k*) ; if this task is allotted to another actor *ai*, with an efficiency $\theta_{i,k}$ in the competence (*k*), the resulting duration will be :

$$d_{a,i} = D^o_i \; / \; \theta_{i,k}$$

Thus an actor may be defined as a profile of competences, trade by trade, and to each competence is associated an evaluation of his efficiency, this efficiency being directly linked to the time needed to perform a given job.

This notion of efficiency remains delicate to handle – its determination, and its use being quite complex and sensitive. Anyway it appears that it cannot be ignored when facing he proble of polyvalence.

In the company, characterization of the efficiency, competence by competence and actor by actor may be viewed from two separate levels : a global level, competence by competence, is the summation of the workforce globally available, and indicates the total resources that can be called to perform all the missions requiring this competence. A local level handles the individual efficiencies for each actor, and the way they evolve with time.

Efficiency and competences : notion of critical competence

Taking into account flexibility in the scheduling of industrial activities requires the identification of all the competences available via all the actors, regardless to their individual efficiencies. At this step, we consider a global competence for every trade of the company : keeping in mind that each of the actors has one or more principal competence (for which his efficiency is 1) and one or few additional competences for which his efficiency is lower than 1, we can consider the company as a whole of competences, intended to satisfy a demand.

Facing a total workload Wi,k, the planner has to perform an evaluation of the global efficiency of the actors likely to provide this workload, in order to determine the global capacity Q_k available. Thus, this global capacity is the summation of all the efficiencies "provided" by the actors in the considered competence :

$$Q_k = \Sigma_a \, \theta_{a,k} \, , \forall \, k$$

The comparison of the different values of Q_k leads us to raise the notion of "critical competence" when it appears that the calculated capacity does not cover the workload for the considered task. We can match here the different schedule constraints industrial activities have commonly to face, which prevent the solution of delaying the workload to cope whith a limited capacity. When the workload ($W_{i,k}$) needed by a task (i) is scheduled on a period the company must respect, the calculation of (Q_k) helps the planner to evaluate whether he has the needed resources or not.

If we call (α) the number of standard work hours in one day for one actor, the respect of the schedule constraint for the task (i) is expressed by :

$$\frac{W_{i,k}}{\alpha * \sum_a \theta_{a,k}} \leq D_i^0 \quad \forall k, i$$

For a given competence, the ratio of the total workload to the sum of the "efficient hours" available to perform it must be inferior to the imparted delay. Thus we can compute the workforce $(E_{i,k})$ providing the competence (k) that must be allocated to the task (i). The ratio $\left(\frac{W_{i,k}}{D_i^0}\right)$ represents the daily workload needed to respect the scheduled duration, and we get :

$$E_{i,k} = \frac{1}{\alpha}\left(\frac{W_{i,k}}{D_i^0}\right)$$

The comparison of $\left(E_{i,k}\right)$ and (Q_k) rapidly indicates if the workforce required is available or not ; The same reasoning applied to the whole project, or to the whole production program, leads us to sort the different competences according to the way they are, or not, sufficiently provided by the workforce allowable.

At this point, the identification of the competences that could be insufficiently available points out the risk that some schedule constraints could not be respected : this means that the planner, who is already facing a classical problem of critical path when scheduling his activities, may consider another form of criticality, depending on the priority he will consider when allocating the different resources on the tasks. From that point of view, the notion of "critical competence" matches the calendar notion of critical task, since choices made on the allocation may result in an impossibility to ensure the total activity duration.

Moreover, at a longer time horizon, the examination of the critical competences overall a great number of activities may provide good indications about the needs for the company to reinforce some of its competences in the future, and to adapt its policy concerning recruitments or continuous education efforts. Some authors [8, 10] have developed approaches of competence modelling, and pointed out its significant importance on the production processes in the companies. Some [10] even presented performance indicators for actors, but without linking it to the duration devoted to performing a task.

Efficiency and actors

In our approach, we consider that every human resource in the company masters at least one main competence, for which his efficiency is 1 – and may offer one or more competences in which his individual efficiency will be a bit weaker. Thus his work allocation may take into account this or these additional trade(s) according to his availability.

Identification of main competences in the companies is traditionally led via an interview, after the examination of the actor's file. But a precise characterization of the additional competences shows to be more difficult, above all when the association of an efficiency measurement is granted [11]. Usually, the efficiency of the actor on a supplementary competence is led empirically through a qualitative appreciation of his know-how – seldom via quantitative measurement of operation time.

In an allocation process, additional competences are only required if the actor is available – thus, tasks allocation in a fist step favours is main competence : a hierarchy of the actor's competences is then needed, which reinforces the demand for a measurement of the efficiencies.

Competences Actors	K_1	K_2	…	K_p	…	K_n
A_1						
A_2						
…						
A_a				$\theta_{a,p}$		
…						
A_m						

Evolution of efficiency

Determination of efficiency is considered as a ticklish problem [11], which leaves little hope about a precise measurement of its evolution : this evolution will depend on the actor's profile, his education, the experience he will have accumulated … Taking all these factors into account, the individual efficiency of an actor may evolve with time to reach the value of 1 and may be appreciated by the quality of work, the ability of auto-appreciating this quality, and by the time needed to perform a given job. We can notice that there is no universal scale for measuring this efficiency : the efficiency, as well as its evolutions, will be appreciated actor by actor, and will be based on the reference to a similar job performed by someone considered as an expert in the same competence. We can also notice that the criteria implicitly referd to for this determination will vary considerably from one trade to another in the same company, and for a given trade, from one company to another.

The main or strategic competences in one company are built along a long individual or collective learning process based on the highlighting of the acquired competences. But the efficiency in one given competence will tend to a limit value of 1 whatever the performance of the actor in his main competence could be. In a work group as well as in any other form of organization, the evolution of efficiency will differ from an actor to another. Work techniques and technologies evolve at a fast rhythm impacting collective and individual efficiencies. This requires from the actors a constant effort for adaptation.

Thus we suggest three milestones in the evolution of an individual actor's efficiency, corresponding to three levels in the progression of his efficiency (figure 1).

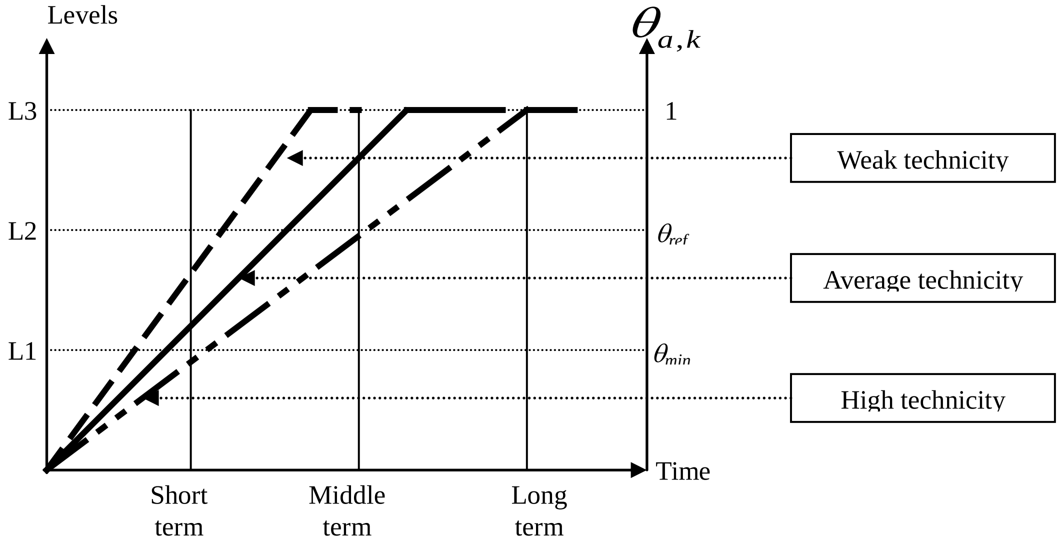

Figure 1 : Levels of efficiency appreciation

Level L1 : discovery level

At this stage, the actor learns to acquire a new competence ; he gets involved and spends his time to master new techniques and basic tools. In this phase, the actor can not practise the learned competence without the assistance of someone in charge of his formation. This is a phase of poor efficiency : $\theta_{a,k} \in [0\,;\theta_{\min}[$. The planer may thus not take this competence into account in his scheduling processes.

Level L2 : maturity level

During the transition between levels L1 to L2 occur a real competence transfer, while the actor masters the basic tools and is able of progressing alone without particular assistance. Along this phase, as efficiency grows up ($\theta_{a,k} \in [\theta_{\min}\,;\theta_{ref}[$), the new resource in the competence is taken into account in the calculation of global capacity – yet the allocation of jobs to this actor will be limited to last extend solutions.

Level L3 : the expert level

In this phase, the actor shows a perfect mastering of the new competence and proves a considerable reduction of operating times – tending towards the respect of standard work durations D^o_i. He is even able to participate to the formation of other actors. His efficiency has reached a level ($\theta_{a,k} \in [\theta_{ref}\ ;1]$) allowing him to be given a priority (when available) on the allocation of missions regarding this new competence.

Economic valuation of the learning process

The total time horizon linked to this competence-acquisition process may be appreciated – being above all related to the technical level of the aimed competence (which can be estimated quite finely), to the “proximity” of this new competence from the actor’s made trade (easy to estimate, too) ; another point that has to be mentioned is the dedication the actor can bring in his learning process, which can be planned and monitored. The main difficulty we have to face is the little quantitative information available from literature about the appreciation of the learning ability of a given human resource.

Yet this whole process will then have to be evaluated economically, in terms of efforts consented by actor as well as his attendants, in charge of assisting his progress …

Evolution with practice

The efficiency evolution phenomena also take into account the fact that according to the resource allocation solutions chosen, a given competence for a given actor may be over – exploited (wich makes him become more and more expert in this field) ; they also can lead to a dangerous drop-down in some practices, giving the opposite result : a progressive decrease of the efficiency due to the lack of experience, or due to the lack of information about technologic evolutions.

Regarding to these aspects, a fine modelling of individual efficiencies involves a precise record of the different practices experienced by every actor in each of his competence. The model presented above about the educational process has to be extended to the competence-renunciation process.

Relations with the scheduling process

The first impact of polyvalence on the industrial activities scheduling process is the disturbance caused to the standard process of dates calculations : this process assumes tasks are characterized by pre – determined durations … which is no longer the case since we may accept, for human resources availability reasons, that tasks have durations depending on who is in charge of performing them. The traditional scope on the critical path is even poisoned in two ways : first, because the fluctuations on tasks durations may induce a fluctuating critical path. It may be impacted too because, depending on the situation of the critical competence(s), priority may be given to the activities demanding the rarest resources, regardless if they are critical or not.

Relation with the economic evaluation

A similar reasoning may be conducted about the planned cost of the industrial activity : the allocation of a non – fully efficient resource on a task increases its duration … and its cost by the same way, at least in terms of working hours dedicated to its completion : the planner will then have to face an even-more complex problem, facing the combinatory of allocation choices, the fluctuation in tasks durations and the fluctuations in tasks costs.

More over, the costs related to the acquisition of new competences by actors has to be investigated in a longer term – and has to be compared to the economic perspectives induced by the development of polyvalence in the company.

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