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From Task Allocation Towards Resource Allocation when Optimising Assembly Systems

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Abstract

The article discusses the question; *is it possible to reach route flexibility and system proactivity through resource allocation and task optimisation.* In order to answer this, differences between three types of optimisation regarding task and resource allocation are discussed: Global Task and Resource optimisation, Task optimisation and local resource allocation, but with resource alternatives, Task optimisation and local resource allocation (optimisation), with prioritised resources, shown as a possible solution in this paper in order to increase the route flexibility and proactivity in the system planning. An example of the last approach will be shown using a logic language (SOP) with help of software tool called Sequence Planner (SP).

Keywords: Task allocation; Resource allocation; assembly systems;Sequence planner; SOP

1. Introduction

To meet the demands on mass customisation, companies have to have a dynamic proactive and flexible production system. In order to handle the planning behind such a system, the sequences of tasks and products through the system can be optimised by computers using optimisation algorithms. In order to do this, the system itself has to be well defined and modelled by a human expert. This human expert, helped by different software tools, is required to create (pre and post) conditions for products, tasks and resources in the system. The aim of these (pre and post) conditions is to express only the minimal requirements when defining interfaces and precedence relations between tasks or availability and need for a specific resource; then the resource allocations and tasks can be efficiently optimised. Time is not always the best criterion to consider when doing an optimisation. If the planning system is aiming to produce only what is necessary rather than maximising the number of products it is possible to optimise towards resource allocation i.e. the resource best suited to assemble will assemble not necessarily the fastest. Furthermore, if the main resource is not available, it is desirable to be able to re-plan and allocate the task to the next best resource i.e. route flexibility. The main issue considered in this paper is: is it possible to reach route flexibility and system proactivity through resource allocation and task optimisation?

Two research questions (RQs) have been formulated:
RQ 1: What parameters need to be defined in order to perform task and resource allocation optimisations?
RQ 2: How can we define the best conditions for proactivity and route flexibility in the system?

2. Background

2.1. Sequence of OPerations and Sequence Planner

The Sequences of OPerations (SOP) language [1] is a graphical language used to specify and visualise relations among operations. This SOP language is based

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on an operation model. Sequences of operations are defined with the help of pre- and post-conditions related to each operation. Fig. 1 presents how an operation for a product can be represented using the SOP language and how a set of operations could be illustrated using Extended Finite Automata (EFA) [2].

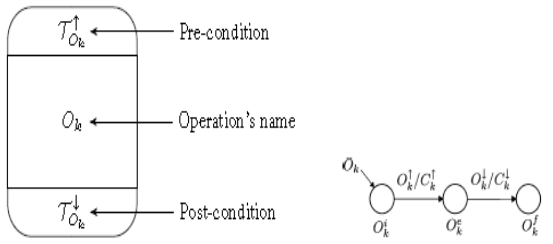

Fig. 1. Illustration of the SOP language and EFA

To be able to perform both task and resource allocation in a more complex system there is a need for software. Sequence Planner (SP) is a prototype software tool developed to manage the Sequence of OPerations (SOP) language and to perform sequence planning [1] SP handles operations and permits to build Sequences of Operations according to pre- and post-conditions associated to each operation. These sequences of operations can be represented from different points of view. For example, SP can represent SOPs from a *product* point of view (sequences of operations related to one product) or from a *resource* point of view (sequences of operations performed by a specific resource).

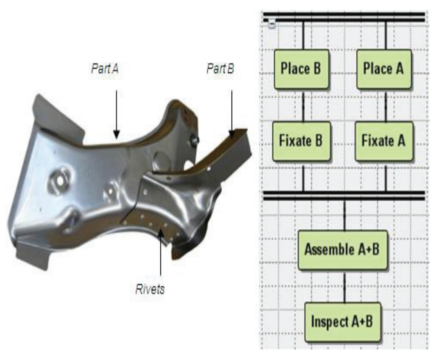

Fig. 2. Example product and its assembly operations illustrated in SP

2.2. Different types of allocations

In order to optimise a system, allocation of operations to different resources must be considered.

In most modern workplaces there is a close sharing of tasks between human operators and machines (technique) [3]. Throughout history there have been numerous definitions regarding how and when to allocate a task or a function and to whom, man or machine?

One of the most common and debated attempt to allocate different tasks to different resources is Fitts list from 1951 [4] which describes humans and machines differences. Fitts [4] thought that using the criteria in his list as the sole determinant of the allocation of functions was to lose sight of the basic nature of a system containing humans and machines. The Fitts list had little impact on engineering design practice because such criteria are overly general, non-quantitative, and incompatible with engineering concepts, and because they assume that functions will be performed by humans or machines alone [3]. Jordan [5] argued whether you could actually compare men and machines; and that the two should be seen as complementary, rather than conflicting, resources when designing a man-machine system. Sheridan [6] suggested to "allocate to the human the tasks best suited to humans and allocate to the automation the task best suited to it". It is only when both human and machine can do the same task, the question of task allocation becomes an issue [7]. There are different allocation approaches that are used in different stages and at different levels at companies;

Task allocation is usually made later, often during system implementation [8]. This type of allocation is often a static allocation based on global optimisation [9]. *Resource allocation* or product/resource mapping means that one or more possible resources are identified for each product operation. The desired degree of flexibility will decide how many alternative resources that is included in this resource allocation and a final choice has to be determined, e.g., by optimization [1].

2.3. Route flexibility

Route flexibility could be defined as;" The ability to reroute a product's path"[10]. This could be explained from a resource- and a product point of view. *Resource view:* To use an operation as an alternative manufacturing step in another production group, if the usual operation and production group are: unavailable or unusable [11], due to a machine break-down or under-capacity [12]. *Product view:* To produce a multitude of products and handle changes in production planning [13].

2.4. Proactivity

Another criterion that is important to consider when allocating tasks and optimising a system is the ability to create proactivity. According to Frese and Fay [14], the focus in design or planning concepts often lies on reactive performance concepts, where static task allocation is performed. Occurring needs and solutions become responses to existing problems, i.e. highly reactive actions. It is questionable whether the reactive approach is sufficiently progressive and competitive. Instead, assembly systems need to be dynamic and evolvable to really constitute long-term assets for the manufacturing company [15]. Proactivity is defined as: "*The extent to which the individual takes self-directed action to anticipate or initiate change in the work system or work roles* [16]"

3. An industrial case example

The problem is that the global task allocation is done in the design phase by the production technicians and in best cases together with the operators. This generates work instructions for the product. The work-leader then has to do a local resource allocation often based on own experience and not in s structured way. A need for a logic planning system for local resource optimization which also generates custom-made work instructions for the optimized path of operations done on a global level with regard to route flexibility as a first step and resources flexibility as a second step.
Global Task optimisation i.e. the order of operations and tasks are determined on a global level

– *Static*

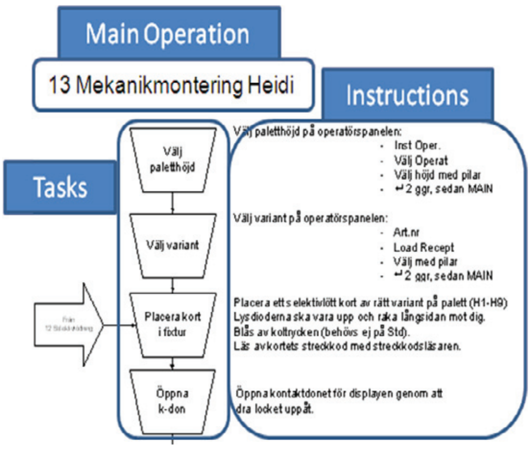

Fig. 3. Example of a global task allocation and assembly instruction

The group-leader is making a competence matrix, illustrated in fig. 3, and then does a "ranking" of resources based on own experience for short time resource planning.

– *Dynamically changeable over time*

List of available operators	Product A Tasks						Competence shown for group leader	Product B Tasks						Competence shown for group leader
Op 1	x	x	x	x	x	x	Jan '08	x	x	x	x	x		Dec '07
Op 2	x	x	x	x	x	x	Jan '08	x	x	x	x	x		Dec '07
Op 3								x	x	x	x	x	x	Dec '07
Op 4														
Op 5														
Op 6														
Op 7	x	x	x	x	x	x	Jan '08	x	x	x	x	x	x	Jan '08
Op 8	x	x	x	x	x	x	Jan '08	x	x	x	x	x	x	Jan '08
Op 9	x	x	x	x	x	x								
Op 10	x	x	x	x	x	x	Sep '07	x	x	x	x	x	x	Jan '08

Fig. 4. Example of a competence matrix used and developed by the team-leader

If these two decision-systems could be performed by the same resource and be dynamically changeable over time; a more proactive system will be developed and the resources' fully potential will be used in the right place at the right time with the right instructions.

4. How can we define the best conditions for proactivity and route flexibility in the system?

What parameters need to be defined in order to perform task and resource allocation optimisations?
In order to create route flexibility and to perform task and resource optimisation, input data from three parameters are defined, illustrated in figure 5.

A set of operations i.e. How to assemble – which operations must be performed on the product and in what order. The order of the operation is globally optimised, based on the pre-and post-conditions related to the product design. This could be seen as a first step of the task and resource allocation.

A set of resources (in this example; R1-R5): with detailed operations. For each resource, each operation that it can realise is detailed through a hierarchical relation.

A resource mapping i.e. who to assemble? - This mapping permits to define and rank, for each operation, which resources are able to realise it. This could be seen as a second step of the task and resource allocation.

This optimization could be performed using three different approaches. The next section will discuss these approaches in more detail.

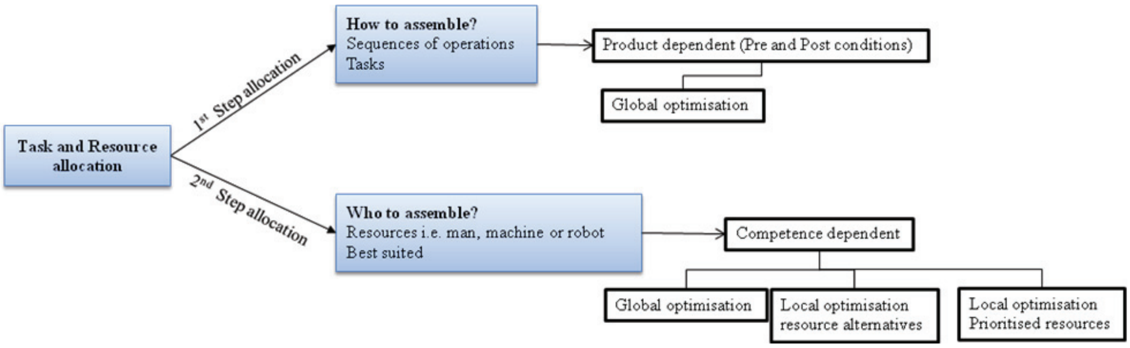

Fig. 5. The two steps of optimisation

5. Task and Resource allocation approaches

In order to answer RQ 1, three different approaches will be discussed when it comes to optimisation and allocation of tasks (i.e. the product view of route flexibility) and resources (i.e. the resource view of route flexibility). Furthermore these three approaches will be discussed in terms of how the parameters tasks and resources (i.e. humans or robots) will be defined. Table 1 shows a summary of the three approaches with regard to how they handle tasks and resources:

1. Global optimisation (containing both tasks and resources) (illustrated as **X** in Table 2) [1, 17]. In this first approach both the needed tasks and the needed resources are optimised at the same time according to the some constraint, often in terms of cycle time.

The two other approaches are divided into 2a and 2b because the task optimisation is the same but the local task allocation differs.

2a. Task optimisation and local resource allocation *with resource alternatives* (illustrated as **Y** in Table 2) [18]

2b. Task optimisation and local resource allocation *with prioritised resources* (**ranking of the resources (R1-R5) from 1 to N, *where* N=4**).

Table 1. Summary of the three allocation approaches

Tasks/Resources	R1	R2	R3	R4	R5
Place A	X Y 1	Y 2		Y 3	4
Place B	Y 1	X Y		Y 3	4
Fixate A			X Y 1		
Fixate B			X Y 1		
Assemble A+B	4	Y 3		X Y 1	Y 2
Inspect A+B	Y 1	4		X 2	Y 3

5.1. Global optimization

This first approach is based on a global optimisation of the sequence of operations. This optimisation is performed taking into account all pre- and post-conditions that are defined, from product design conditions to resource booking conditions.

Global optimisation can be performed according to various criteria, but time is the mainly used criterion [9]. The main advantage of this approach is that the optimised solution obtained corresponds to the global minimum of a cost function. Thus, this solution is the best we can get for the given context.

However, obtaining the optimal solution may need numerous computations. When the size of the system that must be optimised increases; the complexity of the optimisation problem increases too, in the worst case exponentially. Furthermore, the “quality” of the optimal solution we obtained depends on the “quality” of the model used to perform the optimisation. The more precise and realistic the model is, the more realistic the optimal solution is. Unfortunately, to define a more realistic model, lots of additional information must be added to this model, what also increase complexity of the optimisation problem. For large systems, obtaining such an optimal solution can take hours of computation. If an unexpected event occurs (robot breakdown, etc.), the optimisation needs to be performed again to find a new optimal solution. Thus, this decreases the flexibility of the assembly system. Pros with alternative 1 are that it could be done early in the process and if the company only has one alternative resource for each task.

Cons could be that the result of the global optimisation is more or less static and is hard to change later in the process; it is also a risk for “left-over automation” [19].

5.2. Task optimisation and local resource allocation with resource alternatives

A way to tackle unexpected events is to take into account several alternatives for the resource allocation [18]. In this approach a task optimisation is performed taking into account all pre- and post-conditions except those related to resource booking. Then, each operation is allocated to a set of alternative resources. When it is possible, alternative resources should be chosen among different Levels of Automation (LoA). In this example, R1 and R2 are high-LoA resources whereas R4 and R5 are low-LoA resources. In this approach, none of the resource alternatives is prioritised. When the system is executing, the first resource available among the alternatives is allocated to the current operation. Since all alternatives are considered in the same way, the human resource is not considered as a “replacement” resource. These resource alternatives permit to increase route flexibility of the system. Since alternatives consider different LoA, this approach also permits to increase proactivity. On the other hand, since the resource allocation is done locally, it doesn’t permit to conduct a global optimisation. This implies that the obtained planning may not be optimal according to a time optimisation criterion. Pros for alternative 2 are also that it could be done early in the process if companies have few known resources to choose from that are known. It gives a little more dynamic due to changes later in the process. If there are a robot and a human to choose between it becomes more dynamic. Cons with alternative two are that if companies solely want to optimize the system with throughput time as constrain since it focus on flexibility and proactivity.

5.3. Task optimisation and local resource allocation with prioritised resources

This approach is an extension of the previous one. The general idea is the same: a task optimisation is performed without taking into account resource booking condition, and then resources are allocated to different operations. Contrary to the previous approach, resources are prioritised according to a ranking matrix. Different ranking matrices can be defined according to the different policies that can be applied: time, route flexibility, volume flexibility, etc. Fasth [20] have developed a LoA matrix, where the physical and cognitive LoA, current and future needed, could be illustrated and analysed. However, it is common that designers automate every subsystem that leads to an economic benefit for that subsystem and leave the operator to manage the rest [21], to avoid this a global optimisation on task level has to remain. Generally, the manufacturing requirements of the product need to be matched to the capabilities of actual resources. This task/resource mapping means that one or more possible resources are identified for each task. The desired degree of flexibility will decide how many alternative resources must be included in this resource allocation. Among the possible ones, a final choice has to be determined, e.g. by optimisation [1]. There is a need for a dynamic allocation that can take advantage of the access to instantaneous evaluation of the situations to choose the best allocation [22]. In this approach, alternatives resources permit to improve system flexibility and proactivity. The obtained planning may still not be optimal according to total assembly time but the worst solutions can be avoided using priority. Pros for alternative 3 are the opportunity to allocate resources, considering not only time as a parameter but also different states and to make the system more flexible and proactive by ranking resources suitable for the task.

6. How can we define the best conditions for proactivity and route flexibility in the system?

The dynamic resource allocation is performed by adding pre-conditions related to resource booking. These pre-conditions force the assembly system to allocate the operation to one of the different resources.

First, all the alternative resource allocations are added to the SOP previously obtained according to the global optimisation. The pre-conditions defining the selection of sequence among the alternatives can be defined using different criteria. Indeed, the best resource allocation is not always the same; two major features should be taken into account:

1. The resource allocation policy
2. The current “state” of each resource

The resource allocation can be based on a simplistic model such as available/unavailable resources. Such a model can be easily applied if we suppose that there is no resource breakdown, no maintenance task, etc. In that case, a resource could be allocated to an operation as soon as it is available. However, this simplistic model cannot be used to represent a realistic assembly systems, especially if this assembly system is composed of both human and robots resources. The “state” of each resource can be represented using operating modes [18]. For instance, a resource model can be composed of the five following modes: Set-Up, Ramp-Up, Production, Unavailable, and Maintenance. In that case, the resource allocation can be performed according to the current operating mode of each resource. For example, if both a human resource and a robot resource are in their production mode, we can consider that the robot resource is to be prioritised.

7. Conclusions

The aim of the proposed resource modelling is to reduce the gap between a resource and its model, and to take into account human roles in early design phases of an automated system to avoid automation abuse. It is possible if the tasks could be optimised at a global level but the resources performing the tasks will be allocated locally. Furthermore, in order to reach proactivity, dynamically changes in the system have to be possible.

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