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# A METHOD TO IMPROVE DESIGN PROCESS RESOURCE MANAGEMENT

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*Keywords: design process, design resources, project management, process modelling, process improvement*

## 1. Introduction

Product development (PD) projects, and their underlying design processes, call for the integration and interaction of thousands of designers and multiple resources within a careful designed plan [Wynn 2007]. The rising complexity of new products [Lindemann et al. 2009], tight competition, and higher customer expectations demand better processes with shortened delivery times and lower budget. Appropriate resources are not only required to produce a quality product, but also have a significant impact on both project cost and duration. However, design processes are highly uncertain: multiple and unexpected changes yield in iterations and rework that cannot be anticipated at the beginning of a project. In this context, managing resources may become cumbersome. In principle, adding more resources could reduce time to market while increasing cost, but reality of resource planning is notably more complex. Resources to complete a project are usually limited, making its allocation a crucial decision making point. In this competitive environment, appropriate resource management such as resource planning, allocation and scheduling is a key factor to success. Design process modelling and simulation can reduce uncertainty and aid estimation of the cost and duration of design projects by considering rework and iterations probabilities associated to each design task. Several models have been developed with this aim by modelling resources either as constraints or effort. However, most of these models do not account for different types of resource. Yet, distinctive resources (e.g. novices vs expert, number of cores in High Performance Computers 'HPC' etc.) impact differently on process performance and require to be managed in different ways. This paper introduces a new method to model, simulate, and analyse the effect of different resource combinations on process performance in PD.
Section 2 focuses on identifying current modelling approaches that focus on study the impact of resources on design process performance. In addition it will explore what elements have been considered engineering design resources. Section 3 will introduce the new approach, while section 4 introduces a case on which the method is applied, the methodology to analyse it, and results. Section 5 discusses the approach and the results. Conclusion and future work are presented on section 6.

## 2. Background

### 2.1 Resources involved in PD

A study from Xin Chen et al. [2015] drew insights from interviews in an aerospace company and identified that key design resources does not only include designers but also computational, testing and prototyping resources. It argued that design resources are those required to deliver the design. In addition they have availability since the absence of a required resource will be reflected as bottlenecks and delays, or paralyse the project. Moreover, their effectiveness affect process performance metrics. Due to the various properties of different resource (quality, expertise, etc.), their effectiveness could produce different outcomes in performance when executing the same activity. For instance, an HPC could converge an analysis much faster than some stations or desktops, thus impacting on process time. However, the higher cost of HPC could increase project cost.

### 2.2 Methods and models to support design process modelling in resource management

Uncertainty, ambiguity, and risk are inherent in PD and design processes [Pich et al. 2002]. Thus, they are characterised with high iterations, and multiple interdependent activities executed as a multidisciplinary effort [Browning et al. 2006]. In this context, process modelling is often used to describe and analyse the process with the aim of offering insights that could aid managerial decisions [Wynn 2007]. Many models can be found in literature; examples of prominent reviews are Browning and Ramasesh [2007] and Wynn [2007]. In the following, several types of models are described and discussed with regard to their capability in 1) modelling complex and uncertain processes, 2) addressing resource management, and 3) how they treat resources.

#### *2.2.1 Business approaches*

Typical business approaches such as Gantt charts or tools such as Microsoft Project can analyse resource allocation and produce schedules. Basic project management tools have capabilities directed to modelling certain characteristics (e.g. time constraints). They have a descriptive purpose and support for analysis is limited. They do not capture the complexity and uncertainty of design processes. Indeed, the challenge lays on incorporating the uncertainties of design, which requires models that allows iterative analysis [Wynn et al 2007].

#### *2.2.2 Tasks based models*

Tasks based models divide process into a set of activities that must be completed in order to reach the desired objectives [Browning and Ramasesh 2007]. The activities are linked together to represent the information or deliverable flow from one task to another. Tasks networks models include:

- IDEF3 was extended by Belhe and Kusiak [1996] to schedule design activities with precedence and multiple resource constraints, thus treating resources as 'constraints'.
- CPM and PERT have been used to model processes with tasks competing for the same resources, normally taken as a 'constraint'. It allows identifying the critical path to subsequently analyse where and how much resources are needed to minimise delay risks.
- DSM has been used by Cho and Eppinger [2005] for resource scheduling in an advance simulation model. It introduces a weighted parameter to decide heuristically which tasks are more important to execute first in case of resource competition.
- Signposting [Clarkson et al. 2000] and ASM [Wynn 2007] can use resources as 'constraints' during Monte-Carlo simulations of the design process path.

These model considers resource as a ‘constraint’, i.e. as elements needed to be in place to execute activities but limited in number or availability. Other task based models have the capability of estimating the necessary amount of resources. Resources are thus treated as ‘effort’ or any other implicit element that could converge a task or process. Ullman et al. [1997] developed a technique that aids in the decision of where to invest resources. The method has the ability to model stakeholder’s biases and dynamics to decide where the effort (adding resources) should be allocated to increase knowledge and confidence on a decision. Lee et al. [2004] extended DSM to calculate how much resources will be needed to finish a design process in a desire number of iterations. Yassine et al. [2003] used DSM to study design churns, useful to avoid a vicious cycle of firefighting by allocating resources to the identified bottleneck tasks.

#### *2.2.3 Agent-based models*

Agent Based Models (ABMs) consist on a set of entities (agents) characterised by its attributes that interact with each other following defined rules in a given environment [Barbati et al. 2012]. This approach is more concerned with supporting communication, coordination and negotiation of decisions between stakeholders in the design process rather than the structure of the processes. ABMs involve 'human designers'; and sometimes 'tools' used during the process. They are able to model the interaction of design teams including different designer's behaviour and coordinating tasks for resources:

- Agent-based Process Coordination [Madhusudan 2005] helps decision making in planning and task sharing by including a coordinator agent and service agents (CAD, FEA, etc.). The coordinator allocates tasks based on task needs, resource capabilities, and process state.
- Jin and Levitt [1996] extended the Virtual Design Team (VDT), a multi-agent modelling framework to assess configurations of design processes using discrete-event simulation.
- Crowder et al. [2012] developed a collaborative agent based model for simulating teamwork in Integrated Product Teams (IPT), thus treating resources as 'designers'.
- Canbaz et al. [2014] developed a framework to simulate the overall performance of a design process, in which 'designers' have different preferences on design targets.
- CPiW developed by Wynn et al. [2014] can predict the resulting resource requirements and schedule risk of a design process after an externally imposed process change. The model uses agents as 'resources that perform the activities'.
- Hassannezhad et al. [2015] uses Signposting as an agent based model to study socio technical properties of a design process, resources are modelled as 'designers'.

It can be seen that most approaches have treated resources as a constraint for task execution, or for a specific purpose such as to study socio-technical implications. Some challenges still remain unanswered in terms of providing efficient planning and use of different resources.

### 2.3 Challenges and requirements

There is an inherent complexity in deciding what resources should perform which tasks taking into account their effectiveness towards task completion while adjusting to their availabilities. The right resources must be applied to the right tasks in the correct order. These complexities lead to key managerial questions such as: How to predict and optimise future resource needs? Which resource should be allocated if it would be unavailable for subsequent tasks? How can I plan my process around my key resources? Which activities are more sensible towards a change of designer performing it?

Despite all the literature involving resources in design process modelling, often what is considered a resource is not clarified. There is a lack of formal classification of different type of resources in design literature due to the broad definition of the term. Most approaches define resources as elements needed to perform the activities without mentioning their nature. Therefor, it can be designers, money, effort, etc. However, the approaches that mention and model resources characteristics often refer to designers. Thus, it is logical that many researchers have studied the performance of designers [Ahmed et al. 2007], [Crowder et al. 2012] while resources such as computational hardware, software, testing resources, amongst others have been overlooked during process planning stages; and this despite their capital importance towards delivering the product.

We believe that assessing the impact of different resource configurations on the overall project can help answer the above questions, provide further insights on the process behaviour and help decision-making. In this context, process modelling and simulation could help in this endeavour. Nonetheless, as identified, traditional models have overlooked important resources such as computational and testing; and very few can support different type of resources and its attributes. Therefore resource modelling capabilities need to be enhanced, while keeping the ability to capture design uncertainties [Clarkson and Eckert 2010]. These uncertainties are inherent to the design process and can increase the risk of not complying with planned estimations. From the needs, there is a set of requirements that has to be addressed in order to develop such a design process simulation framework. These requirements are:

- Providing the capability to capture design uncertainties.
- Modelling the resources relevant for design processes (computational, designers, testing resources) and providing the possibility to state different resource options for each activity.
- Capturing design resource attributes, and as the relationships between tasks and resources.

- Simulating multiple resource configurations. Analysis should help improve project performance (time, cost, quality), devise insights on the effects of using different resources, and identifying critical resources and resource sensitive activities.

Ultimately the method should suggest and aid on design process improvements to achieve the desired performance. This paper relies on the framework presented by Xin Chen et al. [2015] that introduces relevant engineering design resources and its attributes that affect process performance.

## 3. Method approach

Due to their ability to explore process behaviour and capture the characteristics of design, task network models have shown to be effective in improving design process planning and scheduling. In particular, ASM [Wynn 2007] was chosen as basis to build the approach. ASM is a task network based framework that offers flexibility in terms of implementing behaviour logic and presents an easy diagrammatic visualisation. It can capture design process uncertainties, iterations, product quality progress (parameter refinement), and performance improvements (cost and time). The proposed approach consists in three main steps:

1. Modelling the process, the resources and how the resources are linked to the process tasks
2. Run Monte-Carlo simulations using Design of Experiments (DoE) in order to identify resources combinations that are feasible and yield the best process performances.
3. Replan by changing the process or resource configurations in order to apply learned insights or study different what-if scenarios.

Step 1 is described in the next sub-sections while Step 2 and 3 are addressed through the case study described in Section 5 and 6.

### 3.1 Modelling the design process into ASM

In ASM, the activities can be modelled as:

- *'Simple tasks'*: To represent a task that transforms input parameters into output parameters.
- *'Compound tasks'*: To represent a task that can lead to alternative process routes. They transform input parameters into alternative output parameters from which one will be chosen to carry the design process.
- *'Iteration constructs'*: To represent tasks that can result in success (progress) or failure (iterate).

Tasks are connected to represent the required design path. In addition, design parameters represent inputs from upstream tasks and outputs for downstream tasks. They can indicate the different states of the process and current quality of the product. Finally, the new modelling framework uses resources as process behaviour shapers. The task duration, cost, learning curves, risk of iteration will be determined depending on the resource that completes the activity. The process will start when parameters are at the right state and required resources available. Table 1 shows the task properties that are used as well as the process performance variables measured throughout the simulation.

**Table 1. Task attributes and process performances**

| Process performance | | | |
|---|---|---|---|
| *T* | Total time taken for the activity to finish | | |
| *C* | Cost of the task | | |
| Task behaviour | | | |
| *E* | Effort that takes each resource option to perform the activity | *TI* | If task allows innovation, learning curve after iteration could be present |
| *A* | Availability assign to the task depending on which resource is chosen | *PP* | The urgency to deliver project (e.g. urgent bid or just exploration) |
| *F* | Probability of the activity to fail and requiring iteration | *LS* | If the test slot has been missed |
| *IN* | Number of iterations performed | *W* | Waiting time to perform the task |

### 3.2 Modelling resources

Traditional ASM captures process characteristics within the activities (duration of tasks, risk of iteration, learning curves, and cost amongst the most used ones). Our approach builds on ASM to test the influence of using different resources on process performance. Thus, the activities that allow different resource options will be shaped depending on which option is allocated to perform it. It involves modelling instances of resources that carries out the design activities along with its configurable attributes and tasks requirements. Resources are modelled according to their needs towards the activities. Building on findings from a previous study to identify relevant resources to design processes [Xin Chen et al. 2015], we propose to model four different types of design resources as well as their characteristics:

- *'Human designers'*: Comprised by designers and managers directly involved in the process and activities. They have a level of expertise, a cost, different time perform activities, etc.
- *'Computational resources'*: as hardware (HPC, stations, grids, desktops), software (dedicated to FEA, CFD, etc.), licenses, and network.
- *'Prototyping resources'*: Prototypes will need preparation to be developed and materials to build them. Hence they refer to all materials, equipment, and maybe plants to prepare a prototype.
- *'Testing resources'*. Testing resources comprise those necessary for testing the product. It could include plants, equipment and materials to run tests.

Table 2 abstracts resources and their attributes that affect design process performance found in the previous study [Xin Chen et al. 2015] into functional variables, thus forming inputs for the approach.

**Table 2. Resource attributes according to their type**

| Human designer | | Computational resource | | Prototyping and testing resource | |
|---|---|---|---|---|---|
| *t* | Time initially expected to perform the task | *t* | Time initially expected to perform the task | *t* | Time initially expected to perform the task |
| *il* | Likelihood of iteration inherent to the task and used designer | *r* | Reliability, or failure likelihood of used resource | *r* | Reliability, or failure likelihood of used resource |
| *l* | Designer's learning percentage improvement after iteration of a given activity | *j* | Number of jobs submitted, which can increase waiting time to use the resource | *tl* | Allow time limit for the prototype to be available or ready to be tested |
| *a* | Designer's dedication or availability due to other projects/ commitments | *cu* | Cost per unit time of computational resource | *cu* | Cost of use or per unit time of testing rig |
| *cu* | Cost per unit time of designer | *w* | Normal waiting to use the resource | *w* | Waiting time to book the next testing slot |

### 3.3 Fundamental relationships between resource and task attributes

Fundamental relationships between resource and task attributes was empirically extracted and validated through a preliminary case study in previous work [Xin Chen et al. 2015]. Those relationships influence activity behaviour and process performance, thus the current paper abstracts them into the approach.
The behaviour and performance of a task that allows different resource options will be shaped depending on which resource is selected to perform it, task characteristics and allocation constraints.
Given a set of tasks $n= 1...N$, and a set of resources options as $m = 1... M$ per resource type. When resource is a designer option $m$, its availability a will be translated to the task $n$:

$$A_{n,m} = a_m \tag{1}$$

In the same way the probability of failure $F$ for activity $n$ is allocated as the iteration likelihood of designer $m$ given current task $n$, since it changes depending on task and resource option (Equation 2). When the resource is computational or testing, $F$ for a given activity $n$ follows reliability $r$ (Equation 3):

$$F_{n.m} = il_{n,m} \qquad F_{n.m} = r_{n,m} \qquad (2)\ (3)$$

Effort *E* (Equation 4) is set as time *t* that resource option *m* takes to do the task *n* multiplied by the percentage of decrease (or improvement) in time when the task is iterated (depends on the task and the resource) *l* elevated by the iteration number *IN*. If task does not allow innovation, learning factor will be one.

$$E_{n,m} = Tri\ (t_{n,m}) \times \left(l_{n,m}^{IN}\right) \quad (4)$$

Total time *T* for designers, Equation 5, is obtained by multiplying effort *E* by a factor that captures the availability *a* of designer *m*. In addition, it is multiplied by a factor that captures project priority *PP*. Time *T* for computational and testing resources, Equations 6, is equal to the time of resource option m given task n multiply by project priority. Time is given as a triangular distribution *Tri()*:

$$T_{n.m} = E_{n,m} \times A_{n,m} \times PP \qquad T_{n,m} = Tri\ (t_{n,m}) \times PP \quad (5)\ (6)$$

Waiting time *W* increases as more jobs are submitted from the department to used HPCs. In other words, factor *j* increases as the number of jobs submitted increment:

$$W_{n,m,j} = w_{n,m} \times factor \quad (7)$$

In terms of prototyping and testing resource, if the prototype or design is not ready when the testing slot arrives, then extra waiting time *W* will be needed to reach the next slot:

$$if\ LS = \text{true};\ then\ W_{n,m} = w_{n,m};\ \text{otherwise}\ W_{n,m} = 0 \quad (8)$$

Total cost *C* for designers, Equation 9, accounts for the cost of the designers per unit time *cu* multiple by effort *E* spent on the task. Cost for computational and testing resources, Equation 10, accounts for cost per unit time and the time *t* that the resource is working on the task:

$$C_{n,m} = c_m \times E_{n,m} \qquad C_{n,m} = c_m \times T_{n,m} \quad (9)\ (10)$$

Additionally, when various resources are working on the same task, the time for the task will be the longest taken by the any of the resources used and the cost will be equal to the cost of each resource used added together.
Total process time (Equation 11) and cost (Equation 12) is the sum of the individual task values taking into the chosen options for each task:

$$Total\ T = \sum_{i=0}^{n} T_{n,m} \qquad Total\ C = \sum_{i=0}^{n} C_{n,m} \quad (11)\ (12)$$

## 4. Case study

### 4.1 Process model

Our case-study depicts part of an aerospace project where a set of designers from different backgrounds will need to be selected in order to participate in the design. The model is based on a bigger case study, in which one of the authors was involved. The model was constructed as a simplification of the larger model but including all the key elements that it presented. The process is a 10 task iterative project that involves four designers, one computational resource and one testing resource. The process model, as well as the options for each resources type, are detailed in Figure 1.
The process starts with a set of 3 activities done by preliminary designers, in which different designs are produced with specific tools. Then, mechanical properties are generated and refined in a combined task that involves preliminary and mechanical designers. The product is further studied by an aerodynamic designer, where HPC is involved and failure on aerodynamic performance can iterate the process. Finally, a testing slot was booked in 23 days.
The availability value for an expert designer is 66%, intermediate is 83% and novice is 100%. In addition task times ranges from 2 hours to 1 week depending on the task and it is influenced by which designer is allocated. Cost per unit time value for an expert designer is 6, intermediate is 3, and novice is 1. Similarly cost for HPC is 15 for high number of cores, 11 for medium and 7 for low. Testing slot costs

12 per use. The units used for cost is an arbitrary metric used to denote the value of the resource compared to the others within the organisation, rather than a specific monetary cost, thus it will just be used as 'cost unit'. Iteration likelihood value for an expert designer is 5%, intermediate is 10% and novice is 15%. Waiting time if a testing slot is missed could be 10 days approximately to the next open slot. Learning after iteration is 25% for intermediate preliminary designer. Similarly, learning is 5% for expert, 10% for intermediate and 20% for novice mechanical and aerodynamic designers.
In order to assess and validate the potential benefits of the proposed approach, the above case was also built without detailed resource modelling. The values used for the model without resource combinations is equivalent to using intermediate level in all resource types. Both models were simulated using 1000 Monte-Carlo runs (per resource combination in case of the proposed approach). The next section summarises the results regarding process performance and highlights the differences that have been identified between the original and the resource-based approach.

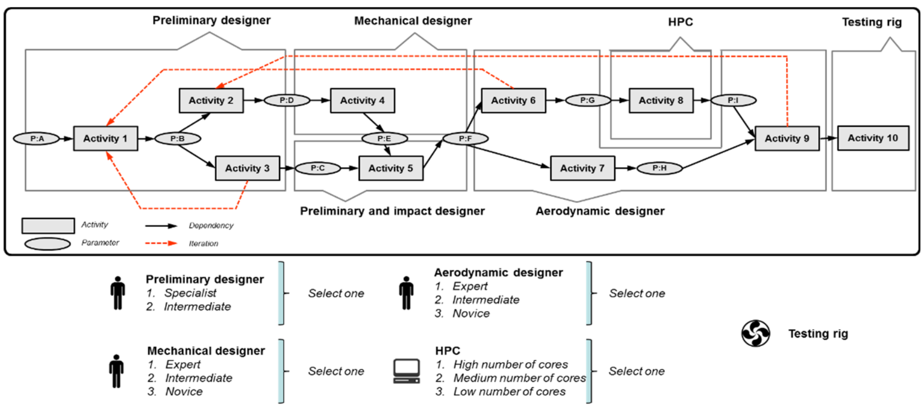


**Figure 1. Design process and resources needed along with possible options**

### 4.2 Results and analysis

The simulation results were gathered and analysed to extract insights for process improvement. Firstly, total process time is compared between the proposed approach and the traditional approach without resource options. Then, process performance is compared within the proposed approach between the different resource combinations. This enables to draw 3 main insights: identification of best resource combination, critical resources, and resource sensitive tasks.

*4.2.1 Comparison of approach without and with resource options*

Figure 2 shows the probability distribution of time performance of all simulations in two histograms: the x axis shows the total time taken by the different process simulation runs, and the y axis presents the percentage of runs that finished at that particular time on the x axis.

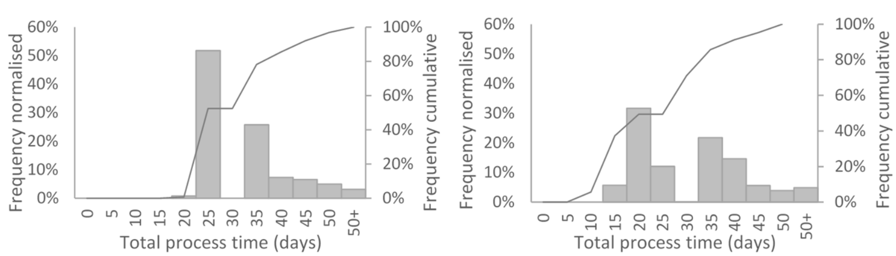


**Figure 2. Total process time histogram comparison of traditional (without resource options) in left and proposed approach (with resource options) in right**

The model using no detailed resource modelling shows less variation compared to the proposed approach. This is due to the standard approach only being able to simulate process performance values equivalent of using intermediate level for designers and HPC cores. With the proposed approach, it is possible to study 54 different resource combinations (scenarios). Thus exploring all variations of design space in terms of resource options. In particular, it can be seen on the histogram that a percentage of runs took considerable more than 30 days to finish the process. They represent the processes that did not reach the testing slot on time, consequently adding 10 days of waiting time necessary to reach the next testing slot. Thus, it seems critical to achieve a process that reaches the testing slot on time.

*4.2.2 Identification of best resource combinations and critical resources*

To identify the best performing resource combinations, firstly total process time performance was analysed, and the set of resource combinations that did not manage to reach the testing slot with a margin of time were discarded (23 days). This left a set of possible combinations. Secondly, taking into account figure 3, which shows different combinations and their total cost, and setting the budget for the process at 125, the remaining combinations could be narrowed down to the feasible ones.

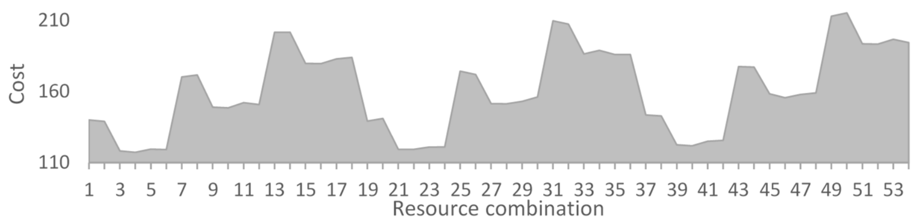


**Figure 3. Different resource combinations total cost**

Thus, a time-cost trade off analysis identified the following resource combinations as feasible to reach the desired process performance:

**Table 3. Time- cost trade off: Feasible resource combinations given performance results**

| Combination | Time (days) | Cost (unit) | Aerodynamics | Mechanical | Preliminary | HPC |
|---|---|---|---|---|---|---|
| **4** | 27.71 | 117.29 | Expert | Intermediate | Intermediate | High cores |
| **3** | 20.39 | 118.25 | Expert | Intermediate | Expert | High cores |
| **21** | 23.24 | 119.38 | Intermediate | Intermediate | Expert | High cores |
| **5** | 22.37 | 119.51 | Expert | Novice | Expert | High cores |
| **23** | 25.82 | 120.99 | Intermediate | Novice | Expert | High cores |
| **Total utilisation %** | | | Expert: 60%<br>Interm: 40% | Interm: 60%<br>Novice: 40% | Expert: 80%<br>Interm: 20% | High cores:100% |

Given cost and time performance aims, high cores HPC and expert preliminary designer seem to be more critical, while mechanical and aerodynamic designers are more flexible.

*4.2.3 Identification of resource sensitive tasks*

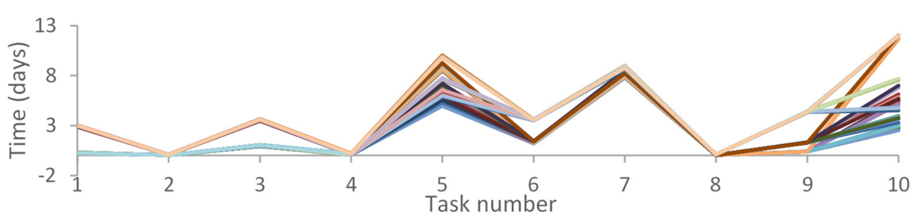


**Figure 4. Different resource combinations time performance in each task**

Figure 4 shows the results of the new approach, in which all possible 54 resource combinations are depicted as a single line each. The x axis indicates the task and y axis the time at which the resource performed the task. The figure enables to identify resource sensitive tasks, those that display very

distinctive performances depending on the different resource used, thus more susceptible to resource changes. In our case, activities 5, 9 and 10 clearly displays such a behaviour; followed by 1, 3 and 6; and less affected by resource changes are 2, 4, 7 and 8.
Due to space limitation other insights will be presented in future work.

## 5. Discussion

The presented case enables to draw three main insights. Firstly, analysis identified the feasible resource combinations given time and cost performance aims. Then, results also distinguished tasks 5, 9 and 10 as more resource sensitive, marking the use of the best performing resources as more critical in order to achieve better performance. In contrast, activities 2, 4 and 8, in which the use of different resources has a lower effect on process performance, have also been identified. They can be proposed as starting activities to train and allocate new or novice designers. In this way, a new designer is introduced to the process while minimising process performance risk. In fact, mechanical designer seems to be the less critical resource, encouraging the introduction of novices. Finally, another interesting insight is how the process behaves when the testing slot is missed, and extra waiting time is needed.
The presented insights in the paper using the proposed approach focuses on planning: before resources are allocated to the project, it is possible to test different hypothetical resourcing situations against a baseline to identify which ones the project would like to acquire. This approach could also be used for scheduling, in which once a set of resources has been assigned to a project, scheduling aims to study how to best allocate them to the activities by exploring other scenarios. In both situations, a set of scenarios can be tested such as increasing/decreasing resources, changing job numbers sent for HPC increasing waiting time, changing resource availability/project priority, amongst others. The difference between planning and scheduling in a simulation point of view, is whether the options are treated as one constraint (planning) or each of them act as a single constraint (scheduling).
However, the approach has a few shortcomings. On the computational simulation side, this type of analysis can be computationally expensive when the number of possible resource combinations is very large. Thus for big models, the activities that have resource options have to identified first instead of allocating options to all activities. On the modelling side, enhancement and more explicit visibility of complex relationships between the different resource attributes, as well as the impact on each other could be insightful. An example could be enhancing resource attributes to depict skills and expertise and their impact on other attributes and performance. Enhancement on relationships modelling would result in increasing the understanding of 1) resource attributes internal dynamics 2) resource influence on task performance, which could draw more insights 3) finally, the method should ultimately allow to constrain any of the resource attributes or process performance values to study the resulting optimal resource combination. It should also allow to describe which resource options could meet specific task and process performance targets.
Future work will be focus on addressing these shortcomings, and further develop the approach.

## 6. Conclusion and future work

Most approaches define resources as elements needed to perform the activities without mentioning their nature. The use of different type of resources (e.g. designers, computational, testing resources) or having a set of resource options in design process modelling simulations have been overlooked. This paper introduces a new method to model, simulate, and analyse the effect of different resource options and resource combinations on process performance in PD. The method had the following contributions:

1. The method models different type of resources used in design processes along with their attributes that affect process performance.
2. The approach allows to allocate and simulate different resource options per task, exploring all the variations of the design space in terms of resource combinations.
3. The analysis shows that such a model enables to identify the combinations of resources that reaches the aim of a desired time (reaching a set testing slot) and budget.
4. Identify resource sensitive activities, which means they have very distinctive performance depending on which resource is used to perform the activity.

5. Perform what if analyses in order to investigate the effect of waiting time changes with number of jobs for HPC, identifying which activities would allow more novices to be trained, etc.

Even though this approach has been presented using the ASM framework, it can theoretically be implemented in any other task-based modelling framework, adding to the method flexibility. Future work will focus on extending the type of analysis that can be done using the approach for planning and scheduling situations, as well as further develop the approach addressing the shortcomings.

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