Concept for competency-based resource allocation in multi-project environments

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Abstract

Many projects in multi-project environments are failing to meet their time and cost goals. To improve the situation it is advisable focus at a core discipline in multi-project management, which is resource allocation of personnel and corresponding project scheduling. Traditional methods often do not take into account the competencies of resources, resulting in suboptimal allocation decisions and lower project performance. To address this problem, there is a need for a competency-based resource allocation method that takes into account the skills and abilities of resources when allocating them to projects. The method presented involves fives steps starting with the description of project goals to enable the evaluation of the proposed resource allocation, followed by assessing the competencies of available resources in a competency model. Next, the competencies required for each project are determined on an activity level. In the fourth step, the impact of the presence or absence of competencies on the processing time of project activities is analysed. Finally, considering individual activity processing times for each resource, an allocation based on an optimization problem is suggested. The approach offers a promising solution for resource allocation in multi-project environments and can be applied in a variety of industries and contexts. Overall, this work contributes to the advancement of the research field on resource allocation in project management and highlights the importance of considering competencies and individual processing times of activities in this process.

Keywords: Multi-project management, resource management, development projects

1. Introduction

Globalization, shorter product life cycles and dynamic changes in the companies' VUCA-environment (Volatility, Uncertainty, Complexity, and Ambiguity) are challenging manufacturing companies, especially in high-wage countries. The consistent increase of competitive pressure manifests in higher requirements in cost and time dimensions as well as a strong need to innovate (Schuh & Dölle, 2021). In order to achieve numerous and fast innovation, most companies significantly increase the number of their development projects (Kopmann et al., 2015). A study shows that the number of projects within the questioned companies increased by 60% in the past years (Müncheberg, 2015). With a higher number of projects, the importance of project success becomes more important for the overall success of the company. More projects fulfilling their goals not only result in better business performance but can also build a competitive advantage by creating new products, improve processes, access new markets and develop new technologies. With this being the case, a common idea is that more projects automatically return more innovation and increase the companies' performance. However, it also leads to more complexity and thereby a higher management effort (Adhau et al., 2012; Babayev, 2017). While it is crucial to finish projects within the scheduled time and cost horizons, it is sometimes unavoidable to create resource conflicts in multi-project environments (Adhau et al., 2012). Studies show that as the number of parallel projects increases, the duration of projects and the number of missed projects goals also tend to be higher (Seidl, 2018). A common but wrong measure is to start new projects earlier to generate a time cushion. However, this leads to new project starting before old projects are finished, increasing the periods of time in which projects run parallel and in return increase the resource conflicts that can evolve and avoidable workload develops (Zulechner, 2015). An additional factor reinforcing delay and additional cost is the dynamic nature of companies' VUCA-environment. This forces them to react to changes, while considering a vast amount of dependencies when restructuring resources in a multi-project environment (Babayev, 2017).

Conclusively in multi-project environments with high-capacity utilization, an efficient and resilient resource management is of highest priority in order to stay competitive (Schuh et al., 2016). This is also highlighted by the fact that in practice many projects are delayed because resources are not available, occupied with higher priority work or just swamped with too many tasks (Dotsenko et al., 2019; Project Management Institute, 2016). Especially experts i.e. resources with a high level of competence are often bottlenecks for the project flow (Techt et al., 2011). Traditionally, resource management has been trying to tackle these problems with a deterministic resource planning approach. Initial project schedules should resolve resource conflicts in advance but especially after inevitable deviations from the initial project schedule, problems arise again. In order to avoid resource conflicts after deviations, the complete project schedule for all projects needs be revised, but traditional project management approaches are too effort-intensive for this. Other approaches use algorithms to support the creation of project schedules like the resource-constrained project scheduling problem (RCPSP) but often these approaches use assumptions and simplifications that prevent them from being used in industrial practice. Therefore, an approach that enables an efficient and flexible resource management capable of short-term changes while ensuring applicability in practice is needed.

The goal of this paper is to outline a concept for increasing the number of projects that meet their time and cost goals by improving the resource management within multi-project environments. The proposed methodology combines the flexibility of lean development approaches with the planning quality of schedule optimization approaches. In order to avoid bottlenecks, resources and project activities are described by the competencies they provide or require, respectively. Based on this, an improved scheduling procedure is developed. Additionally, this paper integrates an analysis of how the allocation of certain resources with an individual set of competencies will influence the processing time of the assigned activity. This new competency-based resource allocation is embedded in an adapted lean development framework based on takt time enabling a continuous control of the multi-project environment and fast reactions to deviations of the initial plan.

2 Terminology

In this section, a common understanding of the relevant terms is outlined.

2.1 (Multi-) Project management

The terms project management, multi project management (MPM) and project portfolio management have been used in similar context around projects (Ponsteen & Kusters, 2015). In general, these terms describe the selection, prioritizing and monitoring of projects within product development. While project portfolio management often refers to the optimal project selection to meet company expectations taking into account all projects, the scope of project management is primarily limited on one project (Mohammed, 2021). MPM is the extension of the (traditional) project management by considering several simultaneous projects including their interdependencies (Dotsenko et al., 2019; Torabi Yeganeh & Zegordi, 2020). MPM has the goal to ensure project success, while staying in the boundaries of time and cost limit. In this regard, MPM is concerned with resource scheduling, measuring KPIs and reacting to deviations (Torabi Yeganeh & Zegordi, 2020). With MPM, handling the complexity of multiple projects under resource constrains while keeping a constant risk evaluation due to uncertainty, the main challenge is to allocate limited resources within a company to optimal usage (Arias et al., 2016; Ponsteen & Kusters, 2015). Another important aspect of project management is the estimation of project durations. In order to be able to plan the duration of a project more adequately and robust, the Project-Evaluation and Review Technique (PERT) was developed. The PERT combines a variability in processing time of project activities with the critical path method (Aziz, 2014). The potential uncertainty in the processing time of an activity is taken into account by including three time estimates for each activity (optimistic, realistic and pessimistic) and deriving a beta probability distribution based on them (Wei et al., 2002).

2.2 Resource and resource management

Resources in project management of development projects are almost exclusively human resources. Resource management is a general term describing the control of certain resources and their usage in an efficient manner. For that purpose, resource management uses allocation strategies as it is used for MPM to allocate project resources as well as strategies to minimize demand peaks and fluctuation (Tran et al., 2016). It is not only a part of MPM, but also used in human resource departments concerning with models describing competencies of human resources. Good resource allocation can make a significant difference in the overall performance of the processes it is integrated in (Arias et al., 2016; Steinle et al., 2010).

2.3 Lean Development

The principles of lean management aim to optimize the economic performance of an observed system. The basic idea was first implemented by Toyota in manufacturing and has become famous in that regard (Trapp & Warschat, 2016). Reinertsen has been significantly involved in applying the lean principles and methods from manufacturing onto project management, in particular the product development. The five principles of lean development are: queue management, batch size reduction, takt time, rapid local adjustments and waste elimination (Reinertsen, 2005; Thomke & Reinertsen, 2012). The lean principles relevant for this paper are queue management, takt time and rapid local adjustments. Queues are created by excessive workloads and denote the activities that still need to be processed for the completion of a project (task). By reducing these queues, cost and cycle times are reduced as well. Secondly, the takt time, which is common in production systems, establishes the process speed and generates a rhythm, which helps the different divisions to synchronize themselves better to the whole system. Another aspect Reinertsen highlights is the importance of the ability to respond and restructure capacities effortlessly to increase adaptation speed in workflows.

3 Related Work

In this section, related work regarding the optimization of project schedules, the competency-based resource allocation and lean development principles in the context of development projects are presented.

3.1 Approaches focusing on the optimization of project schedules

A major topic within the field of operations research is the RCPSP. This optimization problem aims for the minimization of the project duration. The projects contain project activities that must be scheduled subject to previous and subsequent relations and resource constraints. The overall problem is highly variable in its possible characteristics of constraints (Habibi et al., 2018).

Snauwaert & Vanhoucke extend the multi-skilled RCPSP by introducing two dimensions breadth and depth to the skill set of employees (Snauwaert & Vanhoucke, 2021). While the breadth refers to the amount of skills possessed, the depth considers the level of mastery employees archived for a certain skill. Snauwaert & Vanhoucke propose an algorithm to solve the multi-skilled RCPSP, as well as comparing the outlined algorithm to existing algorithms and showing the impact of the solution onto the project duration. However, a procedure for quantifying the impact of the skills or competencies on the processing time of activities is not presented. The differentiated view of competencies taking mastery and amount of competencies into account can be adopted for the use of this methodology.

Haroune et al. develop two heuristics for the algorithmic approach of the RCPSP (Haroune et al., 2021). In this regard, resource allocation in multi-project environments with a pool of different competencies are considered. The different combinations of project activities and resources are quantified by efficiency values, describing the influence of a resource on activities' processing time. While the relation between competencies and activity process times is outlined, the overall focus is solving the actual optimization problem. Thus, a method for the acquisition of the efficiency values is not presented neither is a detailed description of the influence competencies have on the processing times.

3.2 Approaches focusing on the competency-based resource allocation

Nedzelsky introduces the concept of a human resource information set in his research within the resource allocation problems from a project management point of view (Nedzelsky, 2016). The importance and variety of resource allocation in projects is outlined, leading to the conclusion, that the RCPSP algorithms use a small amount of information to assign the resources, while human resources are in return described by a large set of information, including their competencies. In order to tackle this discrepancy, Nedzelsky analyzes the set of information used by different resource allocation algorithms. While Nedzelsky analyzes the importance of competencies for a comprehensive resource scheduling, the impact on the processing time is not considered.

Wysocki addresses the resource allocation for projects, including how to determine and plan resources (Wysocki, 2011). Overall, Wysocki describes several project management approaches, concluding that human resources are the most difficult resource to schedule. In order to address this challenge, a competency matrix describing the competencies of human resources in one dimension and the competencies needed for activities on the other dimension is proposed. Although it is not investigated, how competencies influence process times, the presented matrix can be further utilized in the development of this methodology to display the relation of competencies and activities.

3.3 Approaches focusing on lean development principles

The dissertation of Rauhut is concerned with the implementation of takt time into the product development and therefore the synchronization of development activities for a more efficient and effective product development (Rauhut, 2011). Extending on lean production approaches, the proposed development process with takt time has a high degree of adaptivity due to its modularity and allows efficient replanning at the end of each takt. Rauhut also highlights the possible application of takt time for resource planning in multi-project-environments as an outlook for potential further research.

Korthals also addresses lean management for product development (Korthals, 2014). Korthals describes the general principles of lean management and transfers them to product development. The developed methodology identifies waste during the execution of activities and helps visualizing the value stream throughout the development process. Within this methodology, a model-based description of project activities is introduced, which serves as a basis for the analysis of project activities in the methodology of this paper. Resource allocation and required competencies of project activities are not considered.

The scientific literature emphasizes the importance of resource management for the achievement of project goals. Fig. 1 shows, however, that competency-oriented resource allocation in the context of multi-project management has not yet been intensively investigated. Furthermore, how a resource with an individual set of competencies influences the processing time of an activity has not yet been considered at all. In addition, the simultaneous consideration of project plan optimizations and lean development principles has not been investigated in the scientific literature. By combining an optimization model for project plan generation with the takt time of lean development, the strengths of both approaches are leveraged. There is a research deficit in the development of a methodology that addresses these deficits and explores the potentials created by combining lean development and optimization models.

Figure 1: Related work and the evaluation of covered content concerning this methodology

Key: Consideration of aspects (rows) of the present research project by presented approaches (column)
○ Not considered ◔ Barely considered ◑ Partially considered ◕ Mostly considered ● Considered comprehensively

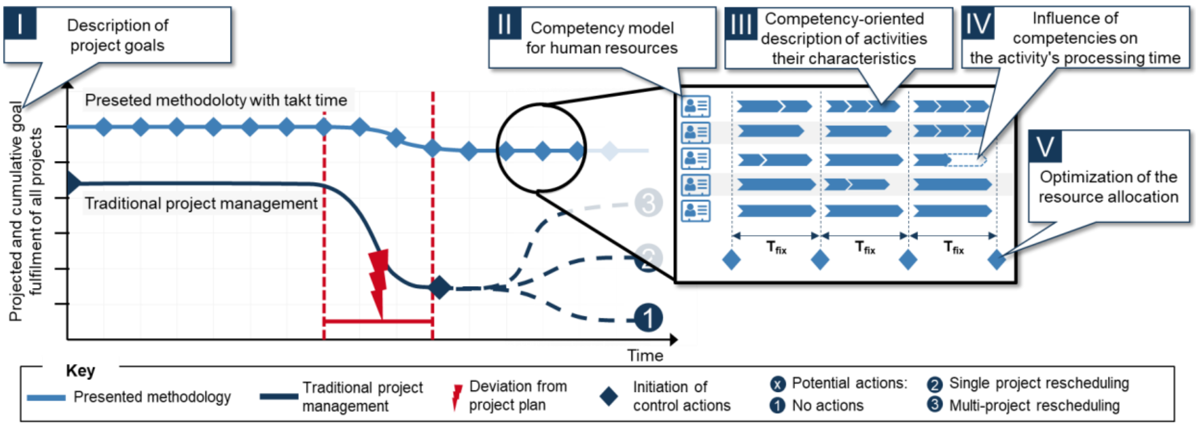
		Optimization of project schedules		Competency-based resource allocation		Lean development	
		Haroune et al. (2021)	Snauwaert & Vanhoucke (2021)	Nedzelsky (2016)	Wysocki (2014)	Rauhut (2011)	Korthals (2014)
Object domain	Consideration of product development	◔	◔	◔	●	●	●
	Consideration of project management	◕	◕	●	●	◕	◕
	Feasibility for multi-project environments	●	◑	◕	◑	◕	○
	Consideration of resource management	●	●	●	◕	◑	◔
Target domain	Cost-oriented consolidation of project goals	◔	◔	◔	◔	◔	○
	Competency-based resource allocation	◑	◑	◑	◑	◔	◔
	Resource-specific processing times of activities based on competencies	◔	◔	○	○	○	○
	Takt time in development process	○	○	○	○	●	◕
	Increase of flexibility with simultaneous cost reduction	○	○	○	◔	◕	◑
SH	Application of optimization methods	●	●	◑	○	○	○

**SH = Solution hypothesis*

4 Methodology

Considering the described situation and the identified research deficits, the overall objective of this paper is to improve the achievement of cross-project goals regarding schedule adherence and resource-related costs by means of a competency-based resource allocation in multi-project environments. For this purpose, aspects of existing RCPSP are combined to a new optimization problem. To plan and control resource allocation it is used in the context of a synchronized product development with takt time. Special focus is given to the question how individual sets of competencies possessed by human resources influence the processing time of a project activity. In the following section, the five-step methodology is outlined as shown in the figure below (Fig.2).

Figure 2: Concept for the improved resource allocation in multi-project environments

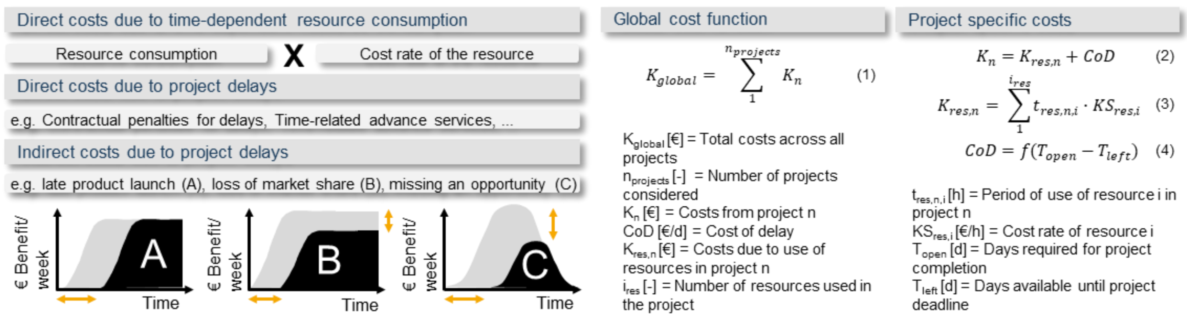


On the left side of Fig. 2 the diagram shows the combined goal achievement of all projects over time. The first step of the methodology describes these goals in order to be able to improve their fulfilment. In the diagram, it is shown that traditional project management approaches react after deviations from the initial project plan are identified. Counteractions mostly focus on the project in which the deviation occurred leading to shifts in priorities or allocation and resulting in resource conflicts with other projects. Only rescheduling considering all projects can assure best project goal fulfilment, but with traditional project management, this is effort-intensive. The new approach presented in this paper is based on a product development with takt time and uses continuous rescheduling at the end of every takt to ensure maximum goal fulfilment. Rescheduling is based on a project schedule optimization model that uses competencies of human resources to assign project activities. Therefore, competencies, activities and the relation between these two are described and determined in steps two, three and four of the methodology. The final step of the methodology develops the mentioned optimization model. The individual steps and their interfaces are briefly presented and explained in the following subsections.

4.1 Step 1 – Description of project goals

To improve the overall achievement of projects goals, they need to be operationalized by making them accessible for optimization models. Therefore, the first step describes the time- and cost-related project goals in a function that can be used within the optimization model in step five. For this purpose, only cost and time aspects that are directly or indirectly influenced by the resource allocation are considered. In order to link them into one function that can be used as objective function in the optimization, time aspects are transferred into costs. This is done by calculating costs of delay, which include direct costs such as contractual penalties and indirect costs such as the delayed profit due to a delay of the product launch. The final cost function considers the time dimension through costs of delay by establishing the difference between target completion time and actual planned completion time and the cost dimension by costs that directly arise from resource allocation such as personnel cost. Based on this function, the optimization will decide if a new project plan will improve the overall achievement of multi-project goals. The formalization is summarized in Fig. 3.

Figure 3: Objective function for the optimization model based on cost affected by resource management



4.2 Step 2 – Competency model for human resources

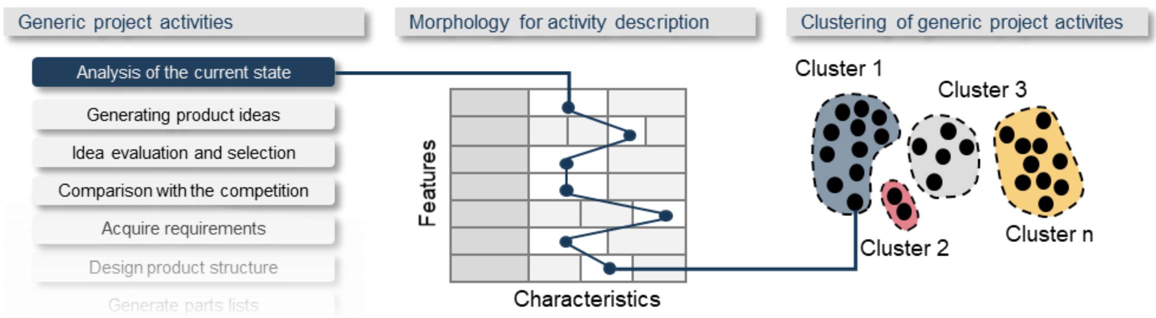
Goal of the second step is to describe the competencies of human resources in the field of product development and to create competency profiles for the human resources. For this purpose, competencies are considered that affect the suitability of a human resource to perform specific project activities and competencies, which influence the processing time for these activities. The development of the competency model follows the method of Krumm et al. and applies the empirical guidelines from Campion et al. (Campion et al., 2011; Krumm et al., 2012). At first, relevant competencies need to be collected. In order to do so, a catalogue of possible relevant competencies is provided and the user of the methodology can choose relevant competencies from there. It is also possible to add further competencies. Second, the competencies must be operationalized by defining levels of competency proficiency and making them assessable by knowledge and skill elements. These information are summarized in fact sheets in accordance with DIN EN 16234-1 (DIN EN 16234-1:2020-02, 2016). Finally, an evaluation process of knowledge and skill elements needs to be defined. Krumm et al. propose different evaluation techniques, for example employee surveys, interviews or behavioral observation as well as combinations of those elements. In addition to defining the different levels of competencies and evaluating the competencies for each relevant employee, further information on each employee needs to be retrieved. These include cost rate, project availability, scheduled vacations as well as other absences and completes the second step.

4.3 Step 3 – Description of activities and their competency-oriented characteristics

In the third step, project activities are investigated. At first project activities are analytically derived and collect from multiple sources of literature. VDI 2221 (VDI, 2019), Dölle (Dölle, 2018), Korthals (Korthals, 2014) or Rauhut (Rauhut, 2011), all include a description of generic project activities in a development environment. The collection can be further extended by activities from case studies of industrial research partners. Based on this collection of activities, a morphology of features and characteristics is developed. The features and their relevant characteristics have to affect the needed competencies to complete the activity. The depth of the morphology should be chosen in a way that most gathered activities could be described by a distinctive set of characteristics. By describing all activities in the morphology, the activities can be clustered based on their characteristics.

Clustering can be based on existing procedures for cluster analysis. In this paper, the three-step procedure of Backhaus et al. is proposed (Backhaus et al., 2018). First, similarities or distances of the considered objects are determined, then a fusion algorithm is selected, in which the objects will be grouped based on their similarities or distance. At last, a defined number of clusters is generated using the found groups. The different descriptions of activities in the morphology serves as distance measurement to execute the algorithm from Backhaus et al. The derived clusters represent groups of activities with similar competency-oriented characteristics. New project activities can be described in the morphology and categorized in one of the defined groups of project activities by aid of the cluster algorithm. The result of step four is a model for the description of project activities and a method to summarize similar activities (Fig. 4).

Figure 4: Description of project activities and clustering them into groups with similar characteristics

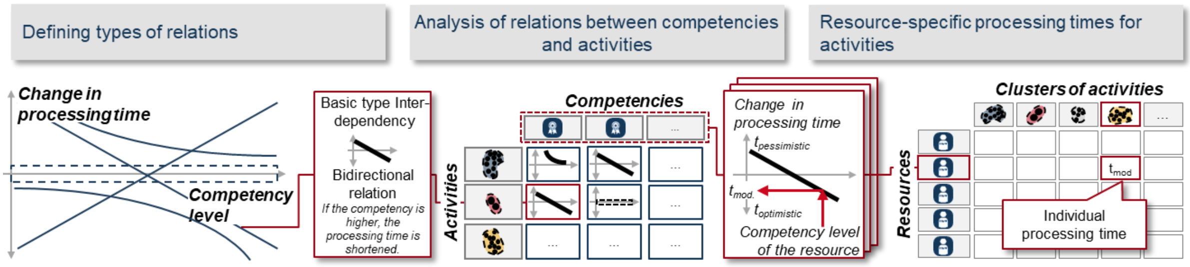


4.4 Step 4 – Determining the influence of competencies on the activity's processing time

The fourth step considers competencies as an influencing factor for the time an activity requires to be done and determines the interdependencies between competencies of human resources and processing time of activities. For this purpose, qualitative relations are described between the clusters of activities and the competencies. These qualitative relations are based on an established typology approach which has been proposed by Kano et al. (Kano et al., 1984). The Kano-Model is highly adaptable and for that reason used in this method to define the types of relations. In the Kano-Model, fundamental types of relations are formed based on the characteristic relation of two parameters. This will be utilized to evaluate each relation between every competency and the processing time of each activity cluster. For this purpose, each combination of competency and activity cluster needs to be analyzed and one of the defined types by the Kano-Model must be assigned. The tool of functional and dysfunctional questionnaire provided by the Kano-Model is adjusted to a qualifying and disqualifying questionnaire that aids the process of assigning a relation. The identified relations are now used to further calculate the specific processing time of each activity for each relevant human resource. Starting point is any given activity, which will be given an estimate for an optimistic, realistic and pessimistic processing time according to the PERT-Method. The activity is described in the morphology from step three and assigned to one activity cluster.

The relations between the activity cluster and the competencies an individual human resource possesses are used to calculate whether the planned processing time is closer to the optimistic, realistic or pessimistic estimate. This can be done with each relevant human resource and each activity to achieve a complete determination of the resource-specific processing time for all project activities (Fig. 5).

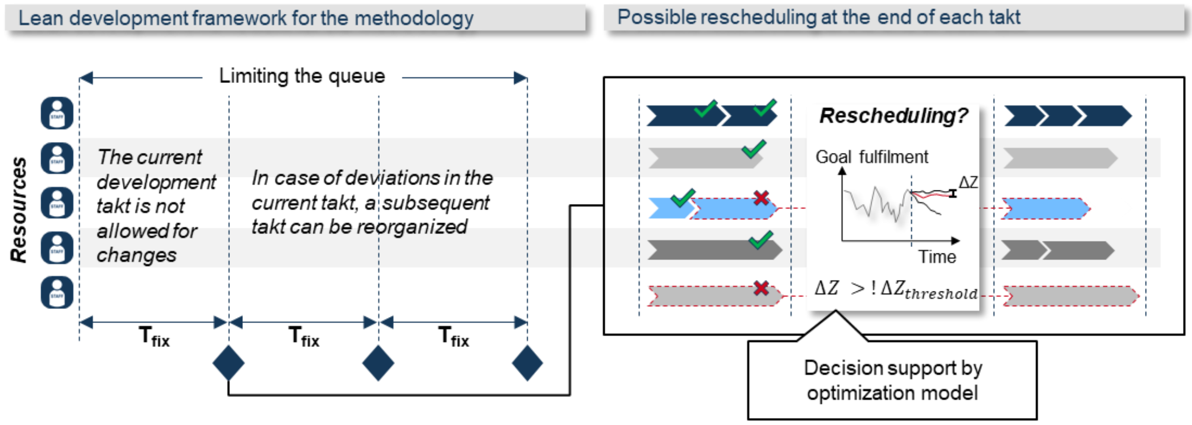
Figure 5: Derivation of resource specific processing times for project activities



4.5 Step 5 – Optimization of the resource allocation

The fifth step uses the results of step one to four as an input for an optimization model. The optimization will be embedded in a development process with takt time according to lean development principles (Rauhut, 2011). The development takt creates intervals at which activities have to be completed and allow the opportunity to reschedule resources at the end of an interval. This will simplify the applicability of the presented method, since the deviation from the plan can be identified in each takt and fixed opportunities at the end of a takt exist to optimize the resources allocation. The goal of the optimization model is to discover the best-possible project schedule. The objective function for the algorithm is the cost function developed in the first step. If the result of this function is minimized, the goal achievement of time and cost dimensions will be improved. The constraints are deducted from the results of step two to four. Since the focus of this research is to outline a methodology, the research will not develop an algorithm and instead use an existing algorithm for the RCPSP from the literature. The result is an optimized resource allocation from the solution of the optimization model with a chosen algorithm from the RCPSP literature. The final element of this step is to transfer und interpret the results from the algorithm in practical application. The results generated are qualitative and serve as recommendation for actions. For example, after detecting discrepancies of the status quo from the initial project plan, the optimization model can calculate shifts of resources to achieve the project goals again, without compromising other projects. This enables the controlling of complex multi-project environments and allows project schedule changes without inducing new resource conflicts (Fig. 6).

Figure 6: Optimization of the resource allocation in a product development with takt time



5. Conclusion

The proposed methodology presents a flexible approach to optimize human resource allocation in a multi-project environment by a five step concept. By introducing processing times of activities that are dependent on the competencies of the assigned human resource, it is possible to create precise project schedules and use human resources with maximum efficiency. Unavoidable deviations from project schedules can be counteracted at short notice by introducing takt time in product development. In doing so, the best possible achievement of project goals in the dimension of time and cost is ensured without causing conflicts of resources.

Future research will focus on the specification of the proposed steps within the methodology and validation in industry case studies. In order to validate the methodology, a demonstrator tool will be developed and enriched by preparatory work and catalogues containing for example predefined competencies. The validation and further investigation of the presented methodology is currently part of the research activities of the authors in the department of Innovation Management at the Laboratory for Machine Tools and Production Engineering WZL at RWTH Aachen University.

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