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Published in:
Procedia CIRP

DOI:
10.1016/j.procir.2016.09.028

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 59 (2017) 89 – 94

www.elsevier.com/locate/procedia

The 5th International Conference on Through-life Engineering Services (TESConf 2016)

Priority rule-based planning approaches for regeneration processes

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Abstract

Regeneration comprises the maintenance, repair and overhaul (MRO) of complex capital goods such as jet engines, wind turbines and stationary gas turbines. Service providers of such regeneration processes face many challenges, including the variability of regeneration paths due to the availability of different repair procedures. In addition, conditions for regeneration processes are defined by the high requirements for logistical performance, e.g., short delivery times and strong adherence to delivery dates set by customers. To meet these requirements, it is essential to efficiently plan regeneration processes. If constraints are not met, regeneration service providers risk heavy penalties and a loss of customers. In this paper, we present methods that, with the aid of priority rules, provide support in planning regeneration processes. These priority rules can be applied to different steps within the planning process: on a higher planning level, priority rules can be implemented to sequence orders and thus to optimize logistical performance. On a more detailed planning level, priority rules can be used to decide on the regeneration path and to schedule the particular regeneration steps. Both successive planning approaches take into account customer requirements as well as targets set by the service provider.

Peer-review under responsibility of the scientific committee of the The 5th International Conference on Through-life Engineering Services (TESConf 2016)

Keywords: regeneration; complex capital good; planning; priority rules

1. Introduction

Complex capital goods such as jet engines, wind turbines and stationary gas turbines consist of a multitude of components with extensive functional interdependencies [1,2]. Because these different components perish during a good's service, it is necessary to carry out maintenance, repair and overhaul (MRO) processes to restore or even improve the good's functionality at the end of its service life. MRO processes in the context of complex capital goods are referred to as regeneration.

Planning internal regeneration supply chains and processes is characterized by several challenges that distinguish the regeneration from common productions. The extent of necessary repair procedures differs due to the specific condition of the capital good. In addition, customers have a strong influence on the possible repair process based on their business model. Therefore, each regeneration order has the character of an individual project. For such a project, there are several possible regeneration paths due to the availability of different repair procedures for specific wear. This increases the degrees of freedom for the planning of regeneration processes. In addition, there are high logistical demands concerning the schedule reliability, short delivery times and strong adherence to delivery dates set by customers. Delay penalties caused by non-schedule compliance need to be avoided because the competitive pressure is very high. To avoid a loss of customers, regeneration service providers have to guarantee high customer satisfaction.

Taking those circumstances into account, our paper discusses methods for planning internal regeneration supply chains and processes. To guarantee a holistic planning approach, two different planning steps are considered. The first step is a rough planning of the order processing considering an efficient logistics process. The second planning step focuses on the determination of a detailed and

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doi:10.1016/j.procir.2016.09.028

resource-specific sequence of the particular activities that are associated with the orders. This approach allows us to take the concretion of information into account. In the first step, only vaguely estimated information is available. The extent of damage and therefore the workload is then determined during a diagnostic phase at the regeneration service provider's site and is considered in the second planning step.

2. State of the art

Figure 1 shows the regeneration process, which can be divided into different subsystems [3]. In addition to the processing, in which the actual refurbishment of the components takes place, the regeneration process includes a disassembly at the beginning and a reassembly at the end of the supply chain. During the disassembly, the partition into the different components takes place. At the beginning of the processing, the components are cleaned and diagnosed. After these steps, the workload and the possible regeneration paths are known for each order. The subsequent repair consists of different repairing jobs depending on the chosen regeneration path. After repairing, the good can be reassembled. A quality assurance at the end of the regeneration checks whether the reassembled good demonstrates the required functionality [4].

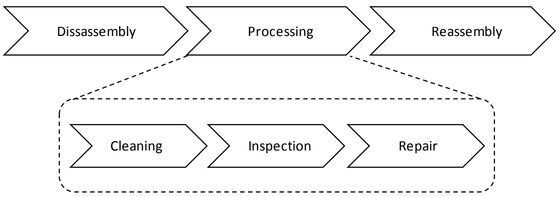

Figure 1 Subsystems of a regeneration process

A survey shows that 41% of the surveyed MRO service providers have problems to adhere the given delivery dates due to time delays within the procurement of components and the repairing processes [5]. This shows that the planning of the regeneration process in MRO companies has room for improvement by taking the specific requirements into account.

In our research, we focus on the configuration of the regeneration processes. The goal is to define in which sequence and in which regeneration mode orders and the corresponding jobs should be processed. Thereby, the competition of different orders for the existing resource capacities must be taken into account. A capacity is scarce if the sum of the overall workload of the orders that could be started at the considered point of time exceeds the available resource capacity.

Regeneration service provider should focus on minimizing turn-around times as well as the arising costs [6]. In our problem setting, the occurring costs consist of the job costs and possible delay cost. In case of missing the delivery date given by the customer, penalty costs for every delayed period arise. In addition, due to the varying repair jobs, each regeneration path is characterized by different costs.

Because of the high variability of the processes due to specific dispatching dates and unknown conditions of the goods accompanied with highly individual customer-oriented regeneration processes, classical planning approaches as, e.g., lot-sizing models are not sensible to solve this problem. Instead, each regeneration event should be interpreted as a project with individual requirements [7]. Due to the in advance uncertain information, it is reasonable to decide which of possible alternatives actually occurring should be chosen instead of forecasting all possible settings. For implementing such a method, one needs rules that prioritize the different alternatives under consideration of the problem setting's objective, so-called priority rules.

Based on the chosen priority rule, a priority value for each order is determined. This specific priority value is interpreted as a rating. Based on this rating, the processing sequence can be determined. Every priority rule embraces one or several criteria. Those criteria include, e.g., schedule-based, monetary or strategic key figures. Priority rules using just one criterion are the easiest way to decide on the sequence. A combination of multiple criteria leads to an advanced planning approach because for each schedulable order or repairing job, a more complex priority value must be calculated. A good overview of different priority rules is given by Browning and Yassine [8].

Admittedly, this usage of priority rules is heuristic, i.e., it is not assured that the optimal solution will be found. However, optimal solution methods like a branch and bound are not able to find a good solution for practical oriented problem sizes with such a high complexity in a reasonable time [9].

In our approach, we distinguish two subsequent planning steps where we apply priority rules. One planning step is to determine which regeneration orders should pass through the regeneration process at what time. The second step includes the fixation of the regeneration path of a specific order as well as the scheduling of the repairing jobs that have to be determined. These steps are described in the next two sections.

3. Priority rules within regeneration planning

Within the planning processes, decisions on the order release must be made at a certain time. In planning on a rough level, the specific resources of the three subsystems disassembly, processing and reassembly are not the focus; rather, the aggregated supply chain is considered. With that, the full internal regeneration supply chain is taken into account. For this reason, the order release should specify the access sequence on the first subsystem.

The goal of this planning step is to achieve high logistics efficiency by realizing the best possible ratio of logistics costs and logistics performance. In terms of logistics costs, minimizing inventory costs as well as minimizing logistics-related process costs are the main targets. For a high logistics performance, short throughput times, high resource availability and high reliability for customer delivery need to be achieved [10]. In general, there is a conflict of targets related to the objectives of low logistics costs and high logistics performance [11].

This trade-off can be faced with measures of capacity synchronization. As machine and personal capacities are limiting factors for order processing, a permanent comparison of available capacity and existing workload needs to be made. The workload of a resource results from the single orders' loads within the planning period. In our operative planning approach, we assume that the capacity is already determined as described in Eickemeyer et al. [12]. In this case, the regeneration service provider has only the opportunity to influence the logistics performance for given logistics cost by postponing or pulling forward orders [12]. Thus, the process step-specific workload created by the order is shifted in time so that the planned start and end dates change.

In deciding which order should be shifted, regeneration service providers evaluate all announced orders and thus fall back on the use of priority rules. Various criteria may be used, such as monetary indicators, the impact on logistics indicators or strategic elements. Only with this capacity synchronization a feasible dispatching based on the available capacities can be made.

Priority rules for this are, e.g., the first-in-first-out (FIFO) rule, the shortest operation time (SOT) rule and the slack time rule. For the FIFO rule, a new incoming order does not change the preassigned sequence, and the schedule deviation can be kept low. As a consequence of the implementation of the SOT rule, the average throughput time is reduced [13]. Because orders with the lowest operation times will be processed, orders with higher operation times will remain within the waiting queue. However, the delivery dates are not taken into account. The slack time rule increases the schedule adherence of the production for the customer because it always prioritizes the order that shows the lowest difference between the planned end date and the cumulative operation times of the remaining resources. Moreover, the selection of the orders that have to be released can be made based on the planned delivery date so that urgent orders are prioritized and pushed into production [13].

Figure 2 shows an example of the discussed problem setting. Having five different regeneration orders available, the regeneration service provider must decide which orders have to pass through the internal regeneration process at what time.

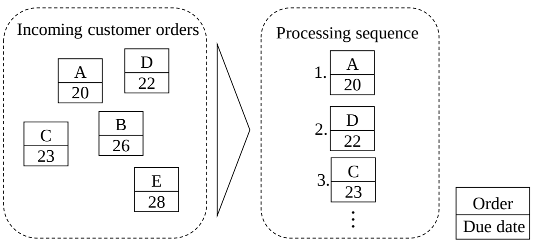

Figure 2 Example of the planning of order sequence

Because schedule adherence is of importance, the orders with the earliest due dates are chosen first, because a delay would cause high cost. In this example, orders A and D need to be processed firstly due to the earliest due date and a given resource capacity. For these orders, the planned start and end dates for the subsystems are calculated. In the next planning step, the repairing jobs of regeneration orders are scheduled in detail.

4. Selection of the regeneration paths and scheduling

4.1. Basic assumptions

On the next planning level, the orders, which consist of different repairing jobs or activities, are scheduled in detail. Due to specific order characteristics, every regeneration process of a complex capital good is unique. This also applies to projects that are unique in the totality of their conditions [14]. Hence, regeneration process of a complex capital good can be interpreted as a project.

The so-called resource-constrained project scheduling problem (RCPSP) describes such a scheduling problem of a single project [9]. For those types of projects, the structure is known in advance and fixed. For the regeneration of complex capital goods, the regeneration path is not known beforehand. A modeling approach for this type of problem is given in the resource-constrained project scheduling problem with a flexible project structure (RCPSP-PS) [15], which is therefore applicable to regeneration processes.

To take into account that the service provider manages orders competing for resource capacities, the RCPSP-PS has been extended to the resource-constrained multi-project scheduling problem with flexible project structures (RCMPSP-PS). The objective of the problem is to minimize the total costs, consisting of the costs for the implemented jobs and the penalty costs for a project's delay.

Figure 3 describes this model using an easy example. It shows possible regeneration paths for the orders A and D, which are released in step one of our approach and therefore have to be planned simultaneously. We assume that after two periods both goods are cleaned and inspected and the order specific workload is known. To adhere to the calculated planned end date of the reassembly that takes one period for each order, the repair of order A must be finished after six periods, and the repair of order D must be finished after four periods. For each delayed period for order A there are penalty costs of one and for order D there are penalty costs of two. Both orders p consist of seven possible jobs j, which are characterized by duration d_{pj} and cost c_{pj}. Additionally, the jobs have resource request k_{pjr} for resource r. The given capacity K_r of this resource is three. Because the first job and the last job of each order are dummies for setting the start and the end of the repair, the duration, cost and resource request are zero for these activities.

In addition to the activity-based characteristics, there are precedence relations among some jobs. In case of a precedence relation between two jobs, the succeeding job cannot start before the other one is completely finished. The arrows in the figure indicate the precedence constraints between the jobs, e.g., job A-6 cannot start until job A-3 is completely finished.

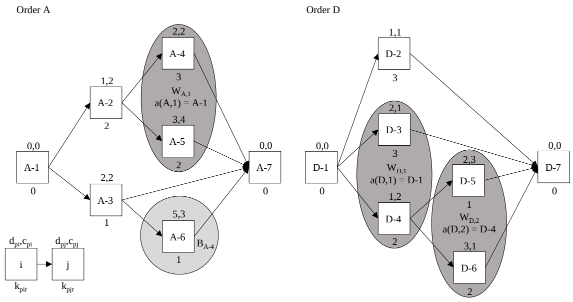

Figure 3 Example of a flexible multi-project

Because the jobs that have to be implemented are not known beforehand, decisions have to be made during the planning. Each decision e is triggered by exactly one job $a(p,e)$. In the case that the triggering job is implemented, exactly one job out of decision set W_{pe} must also be implemented. The residual jobs in the decision set do not have to be implemented. In order A, there is one decision that is triggered by dummy activity A-1. Decision set $W_{A,1}$ includes jobs A-4 and A-5. This means that either job A-4 or job A-5 must be implemented to regenerate the good. Each activity in a decision set can trigger another decision. Order D has two decisions. The second one must be made if and only if, in the first decision, job D-4 is chosen.

Moreover, set B_{pj}, including caused jobs i is modeled. All jobs i in this set B_{pj} have to be implemented if and only if job j is implemented. In order A, job A-6 is caused by job A-4.

For small instances, there are methods for finding the optimal solution as a standard branch-and-bound procedure. Because the RCMPSP-PS, as a generalization of the RCPSP-PS, is NP hard, there is no known algorithm that can find the optimal solution within polynomial time. Therefore, heuristic methods must be developed to schedule real-life instances.

The literature contains different heuristic methods for solving project planning problems. Genetic Algorithms have shown to be able to find good solutions for single project RCPSP-PS instances in a short time [7]. For multi-projects with a fixed structure, priority rule-based approaches are often used [8]. They are promising especially for big instances and have the advantage that they are quite easy to implement in practice, so that we focus on this approach. In the RCMPSP-PS, in addition to the scheduling of jobs, the regeneration paths have to be fixed. This means that two different types of decisions have to be made. Therefore, we solve the RCMPSP-PS in a two-step approach with the use of priority rules. In the first step, the regeneration paths are fixed. After deciding on the regeneration path, in the following step the scheduling of the implemented jobs can be processed. Because the regeneration paths are known before the second step starts, established methods for the multi-project problem with a fixed structure can be used.

4.2. Decision on the regeneration path

To fix the regeneration path, each triggered decision must be made. We developed some priority rules that can be used for the decision on the regeneration path. Depending on the priority rule, the job with the best priority value is chosen. In this planning step, it is not possible to check the adherence to the due dates as the jobs of the different orders are not scheduled yet. For this reason, we take objectives into account that prioritize regeneration paths that are probably short, cheap and/or use little capacity. We present a numerical study on the suitability of the different rules in Section 4.3.

For the SOT rule, the job with the shortest operation time is chosen to find a short makespan. In the example the only decision set of order A consists of two jobs. The duration of job A-4 is two periods, and that of job A-5 three periods. Therefore, job A-4 has a better priority value because it has the shorter duration. With the SOT rule, step A-4 is thus chosen from the decision set. In the first decision of order D, the SOT rule prioritizes job D-4 with a priority value of one. Because this activity triggers the second decision of order D, this decision must also be made. Due to the shorter duration of two periods, job D-5 must be implemented.

In this example, the jobs chosen are those that either trigger another decision or cause another job. These jobs also influence the scheduling. To avoid this extremely myopic effect, in an expanded SOT (ESOT) rule, along with the duration of the job itself, the durations of all caused jobs are added up. If the job triggers a decision, the average duration of the jobs in the triggered decision set is also added. For the ESOT rule, the priority value of job A-4 is computed as the duration of the job itself plus the duration of the caused job A-6. Therefore, the priority value is seven. For job A-5, the priority value is still three. Job A-5 is chosen. In order D, the priority value of job D-3 does not change. Job D-4 triggers the second decision. Hence, the mean value of the job's duration in this decision set must be added to the duration of job D-4. Therefore, the priority value of D-4 changes to 3.5, which is higher than the priority value of D-3. Thus, the ESOT rule prioritizes job A-5 and job D-3.

The resource equivalent duration (RED) rule tries to find the job that has the smallest resource request. The resource request of the jobs must be proportioned by involving the resource capacity. Thus, different resources are made comparable. In addition to the capacity request per period, the duration of the job is taken into account because a large resource request with a duration of one period may be preferable to jobs with a smaller request but a long duration. Therefore, as shown in the formula below, the job's duration is multiplied with its resource request relative to the resource capacity. In this priority rule, jobs with a small resource workload are prioritized. This rule has the goal of finding a short regeneration path in combination with a minimized resource rivalry amongst the existing jobs.

$$\min_{j \in W_e}(d_{pj} \cdot \sum_{r=1}^{R} \frac{k_{pjr}}{K_r})$$

For order A of our example, the priority values of the two jobs in the decision set are equal with a priority value of two. Job A-4 is chosen because the SOT rule works as a tie breaker. The priority value of job D-3 for the RED rule amounts to two, and the priority value of job D-4 is 0.67. Therefore, activity D-4 is chosen, and the second decision of order D is triggered, in which job D-5, with a priority value of 0.67, is chosen.

This priority rule can also be modified to the expanded RED (ERED) rule by taking the triggered or caused activities into account. In this case, for order A, job A-5, with a priority value of two, is prioritized, and for order D, job D-3, with a priority value of two, has the best priority. The second decision of order D is not triggered.

The job costs also impact the total costs. Therefore, the RED rule is expanded to the resource equivalent duration with costs (RED-C) rule by multiplying the penalty costs and adding the job costs. For reducing the myopic effect, the expanded RED-C (ERED-C) rule is considered. For the ERED-C rule in order A the job A-5 with a priority value of six is chosen. In order D the priority value of job D-3 is five. This priority value is better than the priority value of D-4.

For the next planning step, where a fixed regeneration path is needed, the project structure determined by the ERED-C rule is chosen. Hence, jobs A-1, A-2, A-3, A-5 and A-7 of order A and jobs D-1, D-2, D-3 and D-7 of order D have to be implemented. For these regeneration paths, there are fixed job costs of eight for order A and two for order D. Thus, the costs for both orders are ten.

4.3. Scheduling of the implemented repair jobs

After fixing the project structure reflecting the chosen regeneration path, established methods can be used for the scheduling of the repairing jobs. To plan the start and end times of the activities, the parallel schedule generation scheme (PGS) [16] is used. It schedules in every period those schedulable jobs that have the highest priority values. An activity is schedulable if the remaining resource capacity in this period is sufficient and if all predecessors, according to the precedence constraints, are finished. Two priority rules, which performed best in our numerical study, are presented.

We start with the description of the minimum worst-case slack (WCS) rule [16] to explain the PGS. This rule tries to minimize the worst-case slack that may be caused by scheduling a job in the considered period. The basic idea is that due to the limited resource capacities if one job is scheduled, the other temporarily schedulable job may have to start in a later period probably causing a delay of the whole project. The priority value of job j reflects the worst-case impact on the start time of j if another job i is scheduled instead of job j. Therefore, for each schedulable job i the earliest start point of j is computed under the assumption that job i starts in the actual period t. The priority value of job j is then composed of the latest start point (LST) of job j minus the maximum of the computed earliest start points. In cases where the slack definitely leads to a delay, in this paper the priority value is further multiplied with the penalty costs in order to prioritize jobs with higher delay costs. Within this priority rule the job with the lowest priority value is chosen.

The PGS starts at time point t = 0. Because the start dummies do not need the resource and their duration is zero, they are scheduled first. After A-1 and D-1 are scheduled, steps A-2, A-3, D-2 and D-3 can also be scheduled. The priority values of A-2 and D-3 are both zero and better than those of the other schedulable activities. Because the SOF rule works as a tie breaker, A-2 is scheduled first. A-2 uses two units of the resource, so only one unit of the resource is left. The resource requests of activities D-2 and D-3 are larger; therefore, only job A-3 can be scheduled, and it is scheduled. After scheduling A-1, A-2, A-3 and D-1 there are no other jobs that can be scheduled in t = 0. Hence, the algorithm goes on in time. The next decision point is period t = 1 because job A-2, with a duration of one period, is finished; therefore, a capacity unit is again available. A-5 can be started due to the precedence relation. Because of the residual resource capacity, only job A-5 can be scheduled next. Afterwards there is no capacity left and the algorithm jumps to t = 2, where job A-3 is finished. Because there is not enough capacity to schedule jobs D-2 or D-3, the algorithm directly jumps to t = 4. At this time, jobs D-2 and D-3 can be scheduled. Both activities have a priority value of minus six because the priority values of minus three are punished by multiplying the delay costs of two. Due to the smallest duration job D-2 is scheduled next. Figure 4 shows the result after all jobs are scheduled. While customer order A is finished at point t = 4 without delay, order D is finished at t = 7 with a delay of three units. In addition to the fixed job costs of ten, there are penalties resulting for the delay of order D. For each period delayed, we assume costs of two units. The total costs for both orders when the SOF rule is used are 16.

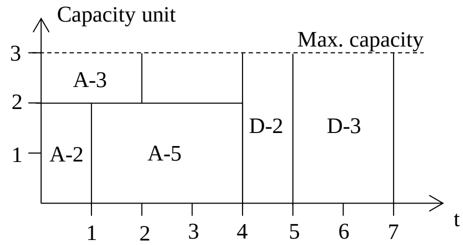

Figure 4 Schedule for orders A and D using ERED-C and SOF

Another priority rule which performs very well is the delay costs with latest start times (DC-LST) rule. The DC-LST rule works in two steps. First, from the set of orders for which at least one job is schedulable, the order with the highest delay costs is chosen. Second, the schedulable job of the chosen order with the smallest LST is scheduled next. Starting the procedure, orders A-2, A-3, D-2 and D-3 are again schedulable in planning point t=0. Because D has the highest costs for delay with two units, an activity of this project is chosen. The latest finishing time of D-3 is smaller than that of D-2, so that D-3 is scheduled.

In a numerical study, the performance of our solution approach is tested. Therefore, for two and eight customer orders that have to be planned simultaneously, we generate 1280 generic instances each. Thereby, a broad variety of parameters is considered to represent many different real-life orders. Every order consists of 15 jobs, excluding the dummy jobs. Each instance is planned by the different combinations of the described priority rules. For a better comparison, in addition to the priority-based method, the instances are solved by a standard branch-and-bound solver CPLEX, with a time limit of one hour. For the two-order instances, CPLEX can always find the optimal solution within this time. However, for larger instances, it is not possible to find the optimal solution. Table 1 shows the performance of the different priority rules in comparison to the results found by CPLEX.

Table 1 Results for the test instances with 15 jobs per order

	2 Orders		8 Orders	
Priority rule	WCS	DC-LST	WCS	DC-LST
ESOT	17.04%	21.72%	-16.07%	-31.35%
ERED	17.61%	22.36%	-17.42%	-32.26%
ERED-C	15.34%	20.48%	-16.62%	-33.11%

For the instances with two orders, the ERED-C rule dominates the other priority rules for fixing the project structures and the WCS rule dominates the DC-LST rule. The combination of the ERED-C and the WCS rule leads to the best result with a gap of 15.34%. It is not surprising that the priority rules lead to worse results than CPLEX for these instances. The rules are designed especially for large instances and CPLEX is able to solve such small instances quite fast.

In the case of eight orders, the situation changes. CPLEX was only able to find a solution for 818 out of 1280 instances. Thereby, the proven optimal solution was almost never found. For the solved 818 instances with eight orders, the DC-LST rule performs best for scheduling the steps. For both priority rules used for scheduling the jobs, the ERED rule performs best for fixing the structures. The best result is produced by the combination of the ERED-C and the DC-LST rule with a gap of -33.11%. This means, that the priority rules perform much better than CPLEX.

5. Conclusion

In this paper, we investigated the planning of the regeneration of complex capital goods. We analysed the general set-up of regeneration processes and identified two planning steps: The sequencing of incoming orders and the more detailed scheduling of the dispatched jobs. For both planning steps, priority rules are able to provide decision support.

Thereby, the selection of an appropriate priority rule for one regeneration provider depends on influencing factors such as the type of customers or the flexibility of capacity restrictions. The priority rule should always be especially tailored on the superior objective. This aim should be pursued across all planning levels. In our approach, we intend a very high logistics performance. On a higher planning level, orders with the earliest due date are selected. In the more detailed planning level, the minimization of the total costs is considered. This objective involves both the processing costs and the penalties for delay, so that the due date is again taken into account.

For further research, it would be interesting to take the stochasticity of the process further into account. In our current approach, we determine the regeneration path based on the information from the inspection. Due to the fact that even after the inspection the workload may be uncertain, it would be a promising idea to select a robust regeneration path which yields to good results for different realizations of the actual workload.

Acknowledgments

The authors would like to thank the German Research Foundation (DFG) for funding Collaborative Research Center 871, “Regeneration of complex capital goods”, which is currently being conducted at the Leibniz Universität Hannover.

References

[1] Kellenbrink C, Herde F, Eickemeyer SC, Kuprat T, Nyhuis P. Planning the Regeneration Processes of Complex Capital Goods. Procedia CIRP 24, 2014, pp. 140-145.
[2] Eickemeyer SC, Nyhuis P. Capacity planning and coordination with fuzzy load information, in: The Global Management. Accounting and Finance Research Conference. The Business Review, Cambrige 16 (1), Washington, DC, USA: The Library of Congress, 2010, pp. 259-264.
[3] Guide VDR. Production planning and control for remanufacturing: industry practice and research needs. Journal of Operations Management 18 (2000), pp. 467-483.
[4] Herde F. Rahmenbedingungen der industriellen Regeneration von zivilen Flugzeugtriebwerken, BoD-Verlag, Norderstedt, 2013.
[5] Reményi R, Staudacher S. MRO: Organisation der Produktion sowie von Produktionsplanung und –steuerung. Ein Blick in MRO-Betriebe mit dem Fokus auf Wartung, Reparatur und Instandsetzung. Wt Werkstatttechnik online 101 (4), 2011, pp. 242-248.
[6] Lee SF, Ma YS, Thimm GL, Versaeten J. Product lifecycle management in aviation maintenance, repair and overhaul. Computers in Industry 59 (2008), pp. 296-303.
[7] Kellenbrink C. Ressourcenbeschränkte Projektplanung für flexible Projekte. Springer Verlag Wiesbaden, 2014.
[8] Browning TR and Yassine AA. Resource-constrained multi-project scheduling: Priority rule performance revisited. International Journal of Production Economics 120 (2), 2010, pp. 212-228.
[9] Klein R. Scheduling of Resource-Constrained Projects. Kluwer Academic Publishers Boston, 2000.
[10] Luczak H, Weber J, Wiendahl HP. Logistik-Benchmarking. Praxisleitfaden mit LogiBEST. Springer Verlag Berlin, 2nd ed., 2003.
[11] Lödding H. Handbook of Manufacturing Control. Fundamentals, Desciption, Configuration. Springer Verlag Berlin, 2013.
[12] Eickemeyer SC, Borcherding T, Schäfer S, Nyhuis P. Validation of data fusion as a method for forecasting the regeneration workload for complex capital goods. Production Engineering Research and Development 7, 2013, pp. 131-139.
[13] Nyhuis P, Wiendahl HP. Fundamentals of production logistics. Theory, tools and applications. Springer Verlag Berlin, 2009.
[14] Deutsches Institut für Normung. DIN 69901: Projektmanagement – Projektmanagementsysteme – Teil 5: Begriffe. Beuth Verlag Berlin, 2009.
[15] Kellenbrink C, Helber S. Scheduling resource-constrained projects with a flexible project structure. European Journal of Operational Research 246 (2), 2015, pp. 379-391.
[16] Kolisch R. Efficient priority rules for the resource-constrained project scheduling problem, Journal of Operations Management 14, 1996, pp. 179-192.