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Evaluating the Logistic Performance Capability of Regeneration Processes

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Abstract**—**For years now, it has been recognized that logistic performance capability contributes enormously to a production enterprise's competitiveness and as such is a critical control lever. In doing so, the orientation on customer wishes (e.g. delivery dates) represents a key parameter not only in the value-adding production but also in product regeneration. Since production and regeneration processes have different characteristics, production planning and control measures cannot be directly transferred to regeneration processes. As part of a special research project, the Institute of Production Systems and Logistics Hannover is focused on increasing the logistic performance capability of regeneration processes for complex capital goods. The aim is to ensure logistic targets are met by implementing a model specifically designed to align the capacities and load in regeneration processes.

Keywords**—**Capacity planning, complex capital goods, logistic performance, regeneration process.

I. Introduction

ALONG with the product quality and price, logistic performance capability is considered a key competitive factor. The logistic performance capability of an enterprise refers not only to the logistic performance, but also to the related logistic costs [1]. Both in the production as well as in regeneration, enterprises have to position themselves between the goals of a strong logistic performance and low logistic costs. In doing so, logistic objectives such as the throughput time, work-in-process (WIP), stock, utilization or schedule reliability are focused on [1]. Current research at the Institute of Production Systems and Logistics Hannover (IFA) is concerned with the planning and control of regeneration processes for complex capital goods and evaluating these processes in regards to their logistic performance capability. Complex capital goods refer to goods in which a number of components are closely related to one another in view of the observed capital good's functionality [2]. This is the case for example with aircraft engines or gas and wind turbines [2]. Regeneration aims to completely re-produce the components that need to be regenerated for a capital good and to either return the good to its original functional efficiency or improve it [2].

With production planning and control there are a variety of methods available for aligning capacities. This procedure coordinates the capacity requirements resulting from the demand with the available capacities [3]. Basically, two different types of methods for aligning capacities can be identified: Available capacities can be adjusted to the accumulating load (e.g., by purchasing additional machinery or introducing an additional shift) or the load can be adjusted to the 'fixed' capacities (e.g., by outsourcing orders or shifting operations) [3]. Combining different methods for aligning capacities fundamentally influences the logistic performance and logistic costs of regeneration processes.

In evaluating the logistic performance capability of regeneration processes, attention is centered on the reassembly. This operation, found at the end of the process chain, re-combines all of the components of the product being regenerated. Reassembly is considered the process element that directly influences the due date compliance [4] and thus also customer satisfaction. Should a part be missing, the corresponding reassembly job cannot be completed. This type of situation arises as soon as one of the regenerated components fails to enter the reassembly system at the planned time. All of the components already available then have to wait for the respective part, tying up capital and leading to increased logistic costs [5]. Furthermore, missing components result in schedule deviations in view of planned completion dates and delivery dates promised to the customer [6]. The reassembly and completion of the regeneration order can only begin once the last component has arrived. Since complex capital goods are at stake here, costly penalties are also to be expected when delivery dates are not met.

In order to prevent these negative outcomes, the capacity planning and control must be designed specifically for regeneration. A number of methods are available for aligning the capacities and loads. In order to be able to draw conclusions about the influence of different methods on the logistic performance capability an evaluation model is required. This model should take into account characteristics specific to regeneration processes and thus be able to serve as a decision-making basis when selecting methods to align capacities.

In the following we will clarify the regeneration specific process characteristics in more detail as well as introduce a model which will be applied to help describe the lateness as well as the WIP situation in an assembly system. Afterwards, the steps necessary for developing an evaluation model for regeneration-specific capacity alignment methods in regard to their logistic performance capability will be described.

II. The Regeneration Process

Generally speaking, a number of process elements can be

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differentiated for a regeneration process. The regeneration process depicted in Fig. 1 is comprised of the main process elements; diagnose, disassembly, appraisal, regeneration, reassembly and quality control [2], [7]. Based on a study of maintenance, repair and overhaul (MRO) enterprises, Reményi and Staudacher [8] were also able to determine that these process elements along with the cleaning of components after the disassembly are the typical steps in a regeneration process.

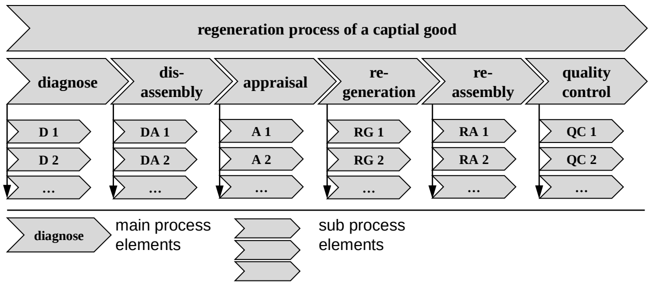

Fig. 1 Main Process Elements within the Regeneration Process [2], [7]

The process elements subordinate to the main processes symbolize different approaches and methods for the respective process steps (Fig. 1). The numerous processes, each conducted differently depending on the regeneration job, cause regeneration processes to be highly complex.

In addition, regeneration is characterized by properties that distinguish it from a common production process and in particular complicate planning and control tasks. Among these features is the fact that information about the required work content is lacking or incomplete when a good arrives. Rather, the information about the scope of the regeneration and thus the work content is first concretely available after the appraisal process [9]. This lack of information complicates the planning and control, potentially resulting in process lateness and ultimately in reduced logistic performance capability. Regeneration also entails the possibility of regenerating and integrating structurally similar and already available parts which were not part of the original regeneration order. Moreover, original parts can be incorporated into the regeneration process and be installed [10]. Planning and controlling the regeneration is also complicated due to the initially vague information basis in regards to the work content. Decisions about integrating original parts and using similarly structured parts that still have to be regenerated are made from regeneration order to regeneration order.

Original parts are drawn upon when the appraised components are so damaged that they can no longer be regenerated or when they are too costly to regenerate and the customer in such cases desires new parts in their product. The original parts do not undergo any regeneration processes but are instead first supplied during the reassembly process.

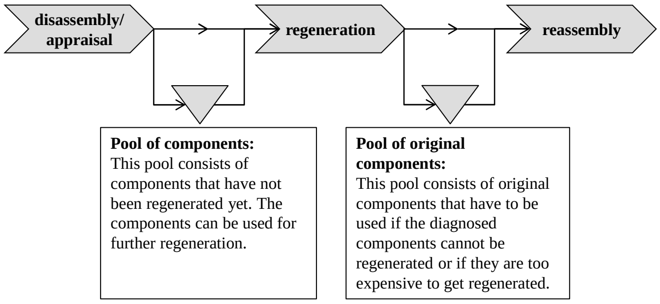

Fig. 2 The Role of Pool Management within the Regeneration Process

Parts from the component pool can be employed when the appraised component can be replaced with a similar component which, for example, is more easily to regenerate. Furthermore, the pool can be drawn upon when the component is appraised as unrecoverable and the customer does not want any new parts to be used. Both when using original parts as well as when relying on parts that still have to be regenerated, the regeneration provider has to retrieve parts from the corresponding pool (Fig. 2). The decision of whether to use new components or structurally similar parts from the component pool mainly depends on how damaged components are the availability of stock and the customer's parameters and desires.

Regeneration orders differ in the number of regeneration, disassembly and reassembly steps required [10]. The work content of regeneration orders thus strongly fluctuates. Depending on damages, different process elements may need to be conducted and additional parts can be incorporated into the regeneration process. The resulting highly complex regeneration processes complicate planning and control and thus also the attainment of logistic targets.

III. The Supply Diagram as a Method for Evaluating Converging Material Flows

The supply diagram is a model which can be used to aid in describing the missing part situation at convergence points in production processes [4]. Such convergence points can be found for example at an assembly operation. Several material flows come together here so that a convergent material flow arises. Since the reassembly within a regeneration process is also characterized by a convergent material flow, this model is in principle transferable to the regeneration.

In order to limit missing part situations in the assembly all required components have to be available at the same time. Only then can an assembly order be completely processed and a corresponding logistic performance capability ensured. Accordingly, the missing part situation in the assembly has a direct impact on the logistic performance [11]. Moreover, the logistic costs are also influenced considerably by missing part situations. Parts in the assembly process, which have to wait for other components due to delays in preceding (upstream) processes, tie-up capital. Additional costs for handling the waiting components and for the use of hall space are also entailed. Components that arrive before the planned date at the assembly process all have to wait to be further processes and thus also cause capital tie-up costs, handling costs and use of space costs [12].

An assembly system can generally be described by the preceding processes. The input of manufacturing orders at an assembly system corresponds to the output on the preceding system [4]. The missing part situation in an assembly is therefore mainly determined by the lateness of upstream processes [11]. From the customer's perspective, the delays that then arise in the assembly directly impact the promised delivery date compliance.

The supply diagram (Fig. 3) depicts the lateness and the WIP situation in the assembly process as a function of the preceding processes' lateness. In order to do so the cumulated value of assembly orders is plotted over the lateness.

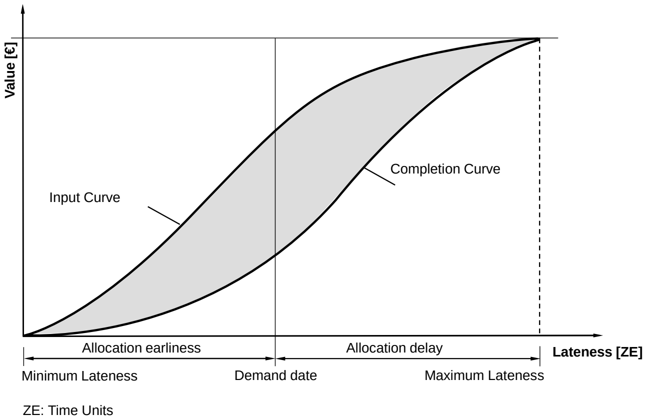

Fig. 3 The Supply Diagram [5]

The supply diagram consists of the input curve and the completion curve, whereby the input curve is based on the output lateness of the preceding process that are weighted with the assembly orders' monetary value. The completion curve maps the lateness of the last component of an assembly order to arrive. The area between the input and completion curves is an indicator for the share of WIP at an assembly system that has to wait for further processing [4]. This share of WIP that is also called the disrupted WIP is again weighted with a monetary value and is therefore refers to the costs being tied up at the assembly. In addition it can be determined which share of the disrupted WIP occurs due to a late or due to a precipitated entering at the assembly system [5].Thus information about the logistic performance and logistic costs can be derived directly from the supply diagram.

The supply diagram is a model that can be implemented to evaluate the logistic performance capability and thus the quality of assembly supply processes [11]. In general, the goal is to have the curves progress so that the input and completion curves are as close to one another as possible and as steep as possible because these characteristics are a sign of a strong logistic performance [13]. Changes of the lateness and WIP situation due to arrangements that influence logistical targets can be easily detected with the help of the supply diagram.

Since the supply diagram allows conclusions to be drawn about the security of the assembly's supply and about the logistic performance capability, it should be possible with its help to evaluate different configurations of design options for aligning capacities in regeneration processes. Nevertheless, the supply diagram was previously developed under the premise of a production process. The model therefore has to first be adjusted to the regeneration specific process characteristics, before the model can be implemented as a basis for evaluating the configuration options for aligning the capacities and loads. With regeneration, the due date and WIP situation of the reassembly is decisively dependent on the regeneration processes conducted before it. The supply diagram is thus influenced by both the lateness of the regenerations process as well as the lateness of the component pool management.

IV. Regeneration Specific Design Options and Their Logistical Evaluation

A method for planning capacities in the long term was already able to be developed with the aid of a comprehensive library of damages as well as the use of Bayesian networks [14]. This approach takes into account the imprecise information that arises in regeneration processes in relation to the scope of regeneration orders and is thus suitable for long term planning.

In order to ensure the capacity planning is comprehensive, additional design options concerned with planning capacities over the short and medium term also need to be considered. The goal of this research project is to develop an assessment model which evaluates the regeneration's logistic performance as a function of different methods for aligning capacities and loads and in consideration of the pool management.

First, the usual methods of adjusting the capacities and balancing the load need to be analyzed. These then have to be extended and adjusted so that they can be transferred to regeneration. In terms of adjusting capacities, capacity reserves and with that the capacity flexibility needs to be considered, whereas with balancing the load in the regeneration process, the focus is on sequencing. The sequence rule that is pursued directly impacts the WIP situation in the assembly and reassembly. Moreover, the implemented sequence also determines the missing part situation [15]. A regeneration-specific sequencing rule should therefore be designed oriented on the missing part situation in the reassembly. The aim is to use a sequencing rule that helps keep the queued WIP's wait as brief as possible in the reassembly even when there are delays in the regeneration process.

Design options need to be considered not only for regeneration processes, but also for pool management. The research project is focused on possibilities both for accumulating pool stock as well as reducing it. Along with this, the safety stock that needs to be maintained in the pool also needs to be accounted for. Due to the lack of information regarding the work content of a regeneration order, designing the provision of individual components is nonetheless challenging. The store outputs resulting from orders are difficult to forecast. Similarly, since replenishment times for components vary it is complicated to precisely project store inputs. A regeneration-specific dynamic method for managing pool stock thus has to be developed. In doing so the availability of information must be taken into account. A first step towards this is provided by methods for the long term capacity planning of regeneration processes. By implementing Bayesian networks the precision in forecasting damages is increased and subsequently also in projecting the anticipated work content of individual regeneration orders [14].

In a further step, it has to be investigated how differently configured design options influence parameters that allow conclusions to be drawn about the logistic performance and logistic costs. Results of the regeneration-specific methods for aligning capacities and pool management are implemented into the simulation model that is required for this. Different configurations of the design options are entered as input values into the simulation model. This results in key logistic performance and logistic costs parameters.

The simulation results then have to be transformed into mathematical functions. These should be considered in the development of the evaluation model. Since the missing part situation, in particular, strongly impacts the logistic performance and logistics costs, the developed function should make it possible to evaluate this situation.

Subsequently, a model is to be developed that evaluates the configuration of alternative options for aligning capacities and balancing loads. Here, the mathematical functions found in the preceding steps will be combined into a single closed model.

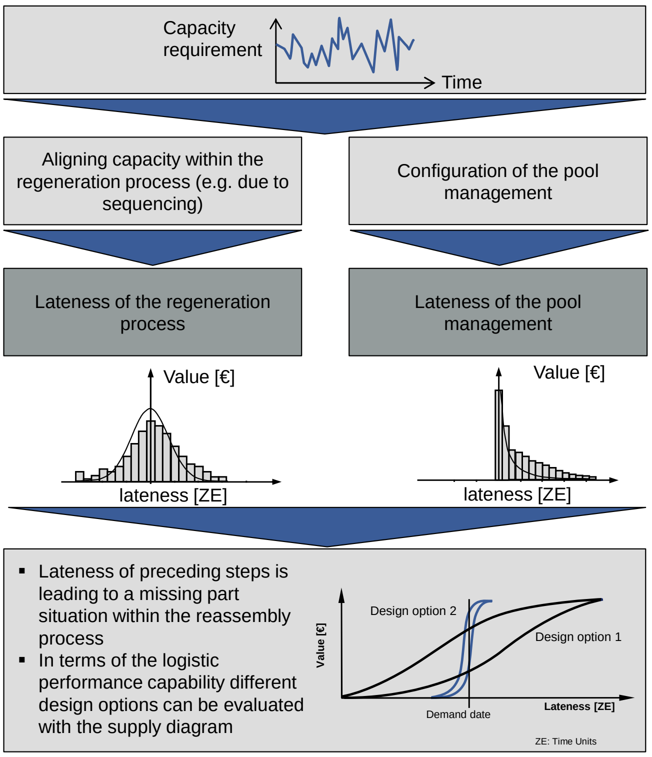

Fig. 4 Key aspects of the Research Project

Taking into consideration the correlations between different design options is an innovative approach. Design options for regenerations processes and pool management along with their interactions are also to be accounted for (Fig. 4).

Depending on the design options the lateness situation as well as the WIP situation within the reassembly process will vary. The supply diagram provides the first step in developing a model that is able to evaluate the logistical capability of such a regeneration process. Nonetheless, the applicability of the supply diagram for regeneration specific processes must first be examined. Moreover, in order to ensure the practical applicability of the evaluation model, the result will be implemented in a demonstrator.

The evaluation model serves the user as a basis for making decisions about how to design measures for aligning capacities and balancing loads. The model offers an approach for assessing the logistic performance capability of regeneration processes through the influence of design options on the missing part situation in the reassembly and in view of mutual interactions.

V. Conclusion

The differences in regeneration processes as compared to the value-adding production pose significant challenges for the regeneration's planning and control. The necessity of meeting these requirements is established in the logistic targets demanded by customers and enterprises. These targets include high schedule reliability from the customer's perspective and short throughput times in the regeneration process.

This paper has introduced a procedure for developing a model which will efficiently evaluate regeneration processes in view of the logistic objectives. An important indicator for the logistic performance capability and for the logistic costs of regeneration processes is the missing part situation in the reassembly. With the aid of a regeneration-specific supply diagram, conclusions can be drawn about the lateness and missing part situation and with that the WIP waiting in the reassembly. The supply diagram thus provides the basis for an evaluation model that can assess different configurations of design options in relation to their logistic performance capability. This evaluation model will be able to help reduce or prevent high capital tie-up costs caused by a large amount of WIP waiting in the reassembly, excessive lateness as well as the resulting conventional penalties.

Acknowledgment

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