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Reducing Wastage In Manufacturing Through Digitalization: An Adaptive Solution Approach For Process Efficiency

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Abstract

The transformation to digital manufacturing has become increasingly critical for companies to remain competitive and achieve efficient manufacturing processes. However, manufacturing operations are often plagued by suboptimal allocation of resources, which can lead to higher costs and lower productivity. Digitalization has the potential to address these challenges by enabling real-time data monitoring, reducing quality costs, and improving process quality.

Previous studies have shown that digital manufacturing can improve the efficiency of manufacturing processes and lead to productivity increases in organizations. However, despite these advantages, many digital innovation projects in manufacturing fall short of their initial ambitions, often resulting in incremental improvements to an existing manufacturing system. This is partly due to the challenges faced by manufacturing companies in quantifying the added value versus the costs of digitization technologies.

Therefore, the objective of this paper is to propose an adaptive solution approach that addresses the need of aiding the decision process in selecting and assessing digital technologies to reduce wastage in manufacturing processes. The approach combines the 'Makigami' methodology, an 'Activity Diagram' (AD) modelling methodology, and a simplified 'Flow Chart', representing an aggregated view of the more detailed AD via a custom modelling schema, into one coherent framework. We further introduce the 'Methods-Misallocation-Measure' (3M-Graph) framework, which maps methods onto elements of wastage and misallocation, and subsequently assigns potential countermeasures. This tripartite mapping facilitates the identification of wastage during process analysis, the allocation of digital optimization measures and eases the assessment of cost effectiveness. The proposed approach aims to improve process efficiency and reduce wastage in manufacturing through digitalization. We conduct a case study of the approach and its application to an industrial assembly station, comparing the initial and then optimized processes. Future work includes the identification of further improvements and extending the framework by methodologies for estimating cost effectiveness more concisely.

Keywords

Digitalization; Efficiency; Cost-benefit analysis; Adaptive approach; Wastage reduction; Process Mapping

1. Introduction

The shift towards digital manufacturing has become increasingly crucial for companies seeking to maintain their competitiveness and optimize manufacturing processes effectively. Nonetheless, manufacturing operations often suffer from suboptimal resource allocation, leading to escalated costs and decreased

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productivity [1], [2]. The adoption of digitalization offers promising solutions to tackle these challenges by facilitating real-time data monitoring, reducing quality costs, and enhancing process quality [3], [4]. Various studies have demonstrated that digital manufacturing can significantly enhance manufacturing process efficiency and foster productivity gains within organizations [4], [5], [6].

Despite these advantages, many digital innovation projects in manufacturing have fallen short on their initial ambitions, often resulting in only incremental improvements to existing manufacturing systems [1]. This outcome can be attributed, in part, to the challenges faced by manufacturing companies when it comes to quantifying the added value versus the costs of implementing digitization technologies [1], [7].

Therefore, the main objective of this paper is to propose an adaptive solution approach that addresses the necessity of supporting the decision-making process in selecting and evaluating digital technologies for manufacturing processes.

2. State of the art

With reference to the state of the art, a collection of approaches exist that aim to introduce digital technologies into production to avoid wastage in a targeted manner. LANZA ET AL. developed strategies for the introduction of Industry 4.0 technologies. This includes the provision of a toolbox with standardized methods such as paperless production in manufacturing [8]. In addition to a description of certain methods, information is provided e.g., about potentials and risks, and prerequisites regarding the implementation level [9]. For the roll-out of digital methods, a quick check is first carried out to determine the degree of maturity in regard to the prevailing digitalization level. Next, maturity levels required by the methods of the toolbox are compared against the surveyed maturity level. Finally, measures for achieving the maturity level required by the methods of the toolbox are identified and conducted [8].

Whilst this approach is high level, other approaches address different process steps separately along the value stream. SALVINETTI adapts value stream mapping for the use within the context of Industry 4.0. The conventional value stream analysis is conducted first, followed by an analysis of the existing and required data ingestion. The same approach is employed for data processing, data preparation and data transfer successively. Finally, the by then digitized process is fully modeled [10].

METTERNICH ET AL. and MEUDT ET AL. extend value stream mapping to include information flow. For this purpose, the information flow is recorded at the level of individual process steps and linked to their media of storage such as paper or ERP systems by applying a Makigami analysis. The intended use of such information is recorded as well. This includes quality management and shop floor management, amongst others [11], [12]. Based on this representation, weak points in the information flow that contradict Lean principles can be identified. For this purpose, METTERNICH ET AL. defined Digital Lean principles of information flows in accordance with the Lean principles of material flows i.e., 'only digitize lean processes' or 'do not allow information flows unless information is used'. The former principle states that material flow must first be optimized before digitization of any processes are considered. The latter principle states that only useful information should be collected, as otherwise it would be considered digital waste. Digital wastage is divided into eight categories, inspired by the eight Muda: data selection, data quality, data collection process, data transfer & transport, inventory & processing times, moving & searching, data analysis, and decision support [11].

Whilst most approaches with respect to the mitigation of wastage tend to focus on using digital technologies to reduce physical wastage in terms of the eight Muda (e.g., [13], [14], [15]), further sources besides METTERNICH ET AL. exist that recognize the importance of capturing and minimizing wastage induced by digital technologies. ALIEVA AND VON HAARTMAN identified three fundamental types of digital wastage: failure to consider expert knowledge of product and processes when collecting data, failure to use collected data to generate information for process improvement, and failure to improve processes despite collected and analyzed data [16]. ALIEVA AND POWELL examine digital wastage within real-world cases and recommend considering it in value stream mapping [17].

Despite these first approaches, there are still several research gaps evident related to the implementation of digitalization technologies in manufacturing processes. Firstly, there is still a lack of clarity on how to implement digitalization in an interoperable way, as pointed out by HODAPP AND HANELT [18]. Secondly, there is a dearth of theoretical studies on how to implement digitalization technologies to achieve data-driven process efficiency in manufacturing processes, as noted by TROPSCHUH ET AL. [19]. Therefore, it is necessary to map digital and physical wastages onto process activities as well as to recommend potential digitalization measures that minimize these wastages.

3. Methodological solution approach

The main goal of our methodological solution approach centers around the idea to ease systematic process analysis and to relax the dependency on expert knowledge. Conventional process analysis heavily relies on experts to create an adequate process description and to identify process inefficiencies, followed by an often-non-formalized process to identify potential mitigation strategies, e.g., brainstorming. Instead, we propose an approach to capture an observed process on multiple levels of granularity with predefined elements in a well-defined manner, which fosters successive analysis steps, and to secondly guide the ideation of mitigation strategies by tripartite graph consisting of "observed methods" – "potential wastage" – "possible measures". Instead of deducing potential measures from observed misallocations (failure mode, cause and effect chain), we propose a solution-neutral approach by starting from unbiasedly observed process methods, then narrow down a collection of potential misallocations linked to the observed process method and finally determine predefined countermeasures linked to the previously narrowed down collection of potential misallocations. Therefore, the main effort during process analysis shifts from a-priori/in-situ perception of process inefficiencies by means of expert knowledge to a-posterior evaluation of devised improvements, which can be conducted by less experienced personnel. To derive our methodological solution approach, this chapter describes our model for describing manufacturing processes, their associated information flow and their subsequently linkage to classic and digital wastage. Section 3.1 explains the inherent problem of choosing a sufficiently but not too finely detailed process model. Section 3.2 presents an adapter layer to combine analysis conducted on different levels of granularity, which is especially useful to connect information flow to physical assembly actions in Section 3.3. This section then discusses the mapping of the associated information flow to the process model. The approach concludes with the formulation of the 3M-Gaph, which assigns possible improvement measures to previously identified wastage in Section 3.4.

3.1 Problem Statement: Choosing an adequate abstraction level

Optimizing manufacturing processes via digital measures poses two main challenges. Firstly, identifying sources of wastage and misallocation, and secondly, determining appropriate countermeasures. In contrast to optimizing physical aspects of a process, operating in the digital domain is especially sensitive to choosing a suitable level of abstraction. For instance, information flows represent abstract concepts only, whereas track-and-trace technologies are heavily hardware-related, and databases incorporate hardware aspects while abstracting information flows and models. Connecting abstract information flow, material flow, manufacturing steps performed by human workers, and process peripheries such as the supply chain in a meaningful and analyzable manner, is still a key challenge for identifying potential sources of wastage as well as for allocating digital optimization measures. Therefore, the abstraction level is subsequently oriented towards shop floor operations (according to withdrawn VDI 2860 [20]), see Figure 1.

Figure 1: Shop floor operations

3.2 Adapter Layer: Aligning operational and informational analysis

To overcome the aforementioned challenges, we propose combining the detail leveled 'Makigami' approach, an abstract 'Activity Diagram' (AD) modeling approach, and a simplified 'Flow Chart', which only depicts aggregated manufacturing actions and methods, into one coherent framework, see Figure 2. Each component serves a specific purpose. The Makigami diagram excels at identifying wastage regarding digital information flow, database architecture, and data modeling, which we broadly subsume under the term 'digital Muda'. In contrast, physical wastage, which can be mitigated via digital measures (e.g., deploying computer vision-based quality control, etc.), can be analyzed more easily in a simple flow chart that only depicts high-level relations. To combine the deep-dive insights of the Makigami diagram with the high-level analysis of a simple flow chart, we interlace both analysis levels via an AD. The AD serves as an adapter layer between the mostly digital and very detailed analysis and the more holistic and mainly physical analysis. Ideally, the detailed process flow of the AD can be clustered, thus directly forming the simplified flow chart.

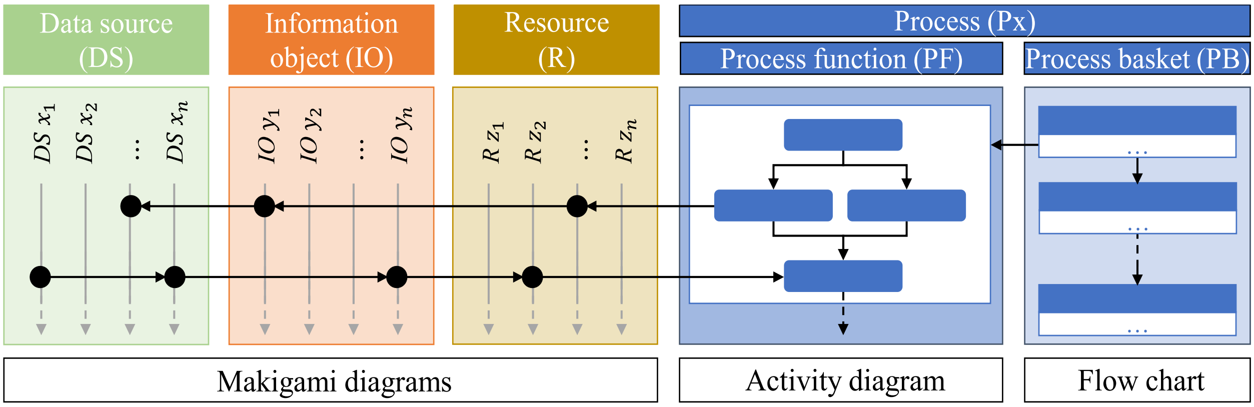

Figure 2: Framework for MAM-Chart approach

3.3 MAM-Chart: Fusing 'Makigami-Activity-Method' into a holistic approach

Whilst Makigami and AD are well defined approaches, we experienced that it is difficult to choose an appropriate level of abstraction regarding the flow chart. The family of industry standards such as i.e., VDI 2860, DIN 8580 and DIN 8593 [20], [21], [22], deliver a solid basis in terms of well-defined standards and terminology to build upon. Whilst the already mentioned industry standards define broader families of process actions and then quickly deepen into very specific terminology, we employ an intermediate terminology more appropriate for clustering and aggregating the AD process description. The implementation of this intermediate terminology is indeed use case specific but geared towards MTM-UAS (Methods-Time Measurement - Universal Analysis System) in terms of abstraction. Thereby, this intermediate terminology represents a collection of 'methods' (in terms of clustered manufacturing steps), which we call “process basket”, see Figure 2 right column. Whereas the AD and flow chart are interlaced via their clustering relation, AD and Makigami are interconnected via depicting flows, sources, and media of data. We therefore extend the standard Makigami approach by building upon the scheme ‘data source (where the information originates?) – information object (what the information is about?) – resource (how the information is actually conveyed?)’. Firstly, one Makigami is utilized to list data sources accessed within the scope of the process to be optimized. This Makigami in turn maps onto a second Makigami only depicting different types of information objects (e.g., order ID, part number, sequence number, etc.), which then maps onto a third Makigami containing only resources such as worker, parts, tools, etc. The third Makigami then finally connects to the actual AD process flow, see Figure 2. By doing so, handovers into multiple information objects or duplicate data sources can easily be identified. Finally, the AD serves as an adapter between the Makigami relations and the clustering into a simplified flow chart. We refer to this three-parted approach as ‘MAM’-Chart.

3.4 3M-Graph: Linking ‘Methods-Misallocation-Measure’

Whilst above mentioned MAM-Chart comes in handy for identifying wastage, it is not particularly useful for assigning (digital) measures to already identified wastage. Therefore, we propose a second framework building upon the MAM-Chart by mapping methods (from the ‘process basket’ used for the simplified flow chart in the MAM-Chart, Figure 2 most-right column) onto elements of misallocation and wastage, which in turn are mapped onto potential countermeasures. Thereby, we form a tripartite graph consisting of assigned triplets of [method, misallocation, measure], wherein we refer to ‘method’ in terms of clustered manufacturing steps (see above). Even though the 3M-Graph depicted in Figure 4 is tailored to a specific use case, the 3M-Graph can be generalized to support a wide range of process optimization. Furthermore, the 3M-Graph can be extended by additional methodologies to estimate costs and potential benefits of measures listed in the most-right column of Figure 4. Within an industrial process optimization workflow, firstly, a MAM-Chart would be created with the specific use case in point. Secondly, based on this process mapping and the acquired methods (see ‘process basket’ in Figure 2 most-right column), potential misallocations and wastage can be gathered (see middle column of Figure 4) and compared to the MAM-Chart. Thirdly, appropriate countermeasures can be identified by the right-most column of the 3M-Graph (see Figure 4). Not yet implemented, but conceivable for the future, suggested estimation methodologies for costs and benefits can be linked to each measure to guide the decision-making process when it comes to choosing appropriate optimization strategies.

4. Evaluation

The approach described above is examined as part of a case study using a real-life example, which is discussed in this section. The example depicts the pre-assembly process of a front bumper within one of the leading European commercial vehicle manufacturers. In section 4.1 the real-life example is described in detail. In section 4.2 we evaluate the MAM-approach by an excerpt of the results from section 4.1 with regards to the process modelling as well as the corresponding information flow. Afterwards wastage was identified and added to the MAM-model. Finally, potential countermeasures were derived from an exemplary 3M-Graph in section 4.3. The final remarks and conclusion are presented in Section 4.4.

4.1 Description of the use case and the manufacturing process

In this process, workers first need to identify the order of assembly and the assigned assembly duration per order from an overview list by themselves. Then, workers stamp on a paper printout to confirm the assignment of the order to their unique ID. Next, workers search for an order-specific bill of material, which serves as an overview to determine which parts need to be assembled at which location on the assembly (e.g., right vs. left hand drive) as well as the parts’ location in the logistics supermarkets. From a nearby supermarket, all necessary components are successively picked into an assembly trolley and brought to the assembly station. This procedure must be done at least twice. Workers then pick up an assembly rack to load it with the basic structure using a manipulator. The assembly rack is then moved to an assembly workstation as well. Next, the actual assembly is carried out at the assembly workstation. After the assembly is done, workers move the assembly trolley with the pre-assembled bumper to a Q-Gate. There, plug connections, scratches or further damage are manually checked. In addition, the installation of the radar sensor must be confirmed by scanning a data matrix code. Finally, workers place the pre-assembled bumper in the correct spot and sequence within a buffer zone, which is then emptied again by other workers from the main assembly line using the pull principle. The whole pre-assembly of the front bumper takes between 20 and 35 minutes, depending on the variant. To apply the approach consisting of the MAM-Chart and 3M-Graph, an on-site inspection was carried out. During modeling, the higher-level process steps were first recorded in the correct order (see 'process basket' at the MAM-Chart, Figure 2 most-right column). Then the objects of the respective Makigami diagrams (data sources, information objects and resources) were determined based on the process observation. In the next step, the process building blocks were refined by modelling them in an AD (adapter) and linking them to the Makigami diagram. For reasons of clarity, only an excerpt of the entire process is shown in this paper, which is visualized in Figure 3. The excerpt ranges from the beginning of the process (finding the right order to assemble) up to the end of the part picking in the supermarket. The loading of the basic structure, the assembly process in and of itself, the Q-Gate, the scan of the radar sensor as well as the sequencing into a buffer zone are not analyzed in this paper.

4.2 Evaluation of the MAM-Chart connecting process and information flow

For the examined excerpt of the pre-assembly, delay times due to the order acceptance sub-process, searching for information on the printout, and searching for the appropriate bill of material, were identified as conventional wastage. Furthermore, the movement of the assembly trolley per se represents an unnecessary transportation loss (misallocated worker time). Due to the undersized assembly trolly, multiple walking cycles are required, resulting in overprocessing during part picking. Because of the insufficient worker guidance, the dependency on implicit knowledge of the workers is identified as a weak point from the Makigami diagrams. Furthermore, it can be observed that digital information is transformed into an analogous media format (printouts). In addition, extra analog information is then generated by a stamping procedure. An a-posteriori data analysis would require additional digitization of this data. Additionally, data is required repeatedly. For example, the order ID is referenced several times in the process but is transferred via different documents. Finally, data is presented and interpreted without any reference context during the picking process.

4.3 Evaluation of the 3M-Graph for deducing potential countermeasures

By identifying possible wastages within the observed process and by employing the 3M-Graph approach to our use case (see Figure 4), countermeasures were compiled to mitigate process inefficiencies. The dotted red line in Figure 4 constitutes one exemplary instance. To confirm orders without stamping printouts (analog data), the 3M-Graph proposes to use Worker ID cards as authentication method. Thereby, digitally captured data can easily be analyzed without resulting in higher process times and by also adding timestamps. Figure 4 also contains further combinations to reduce wastage like substituting the paper printouts with a smart watch. A smart watch would display a worker guidance system to assign orders to workers by using live data and the actual shift performance. The depicted 3M-Graph does not claim to be exhaustive. Depending on the use case, the graph must be adjusted and extended accordingly by the analysis of the case in point.

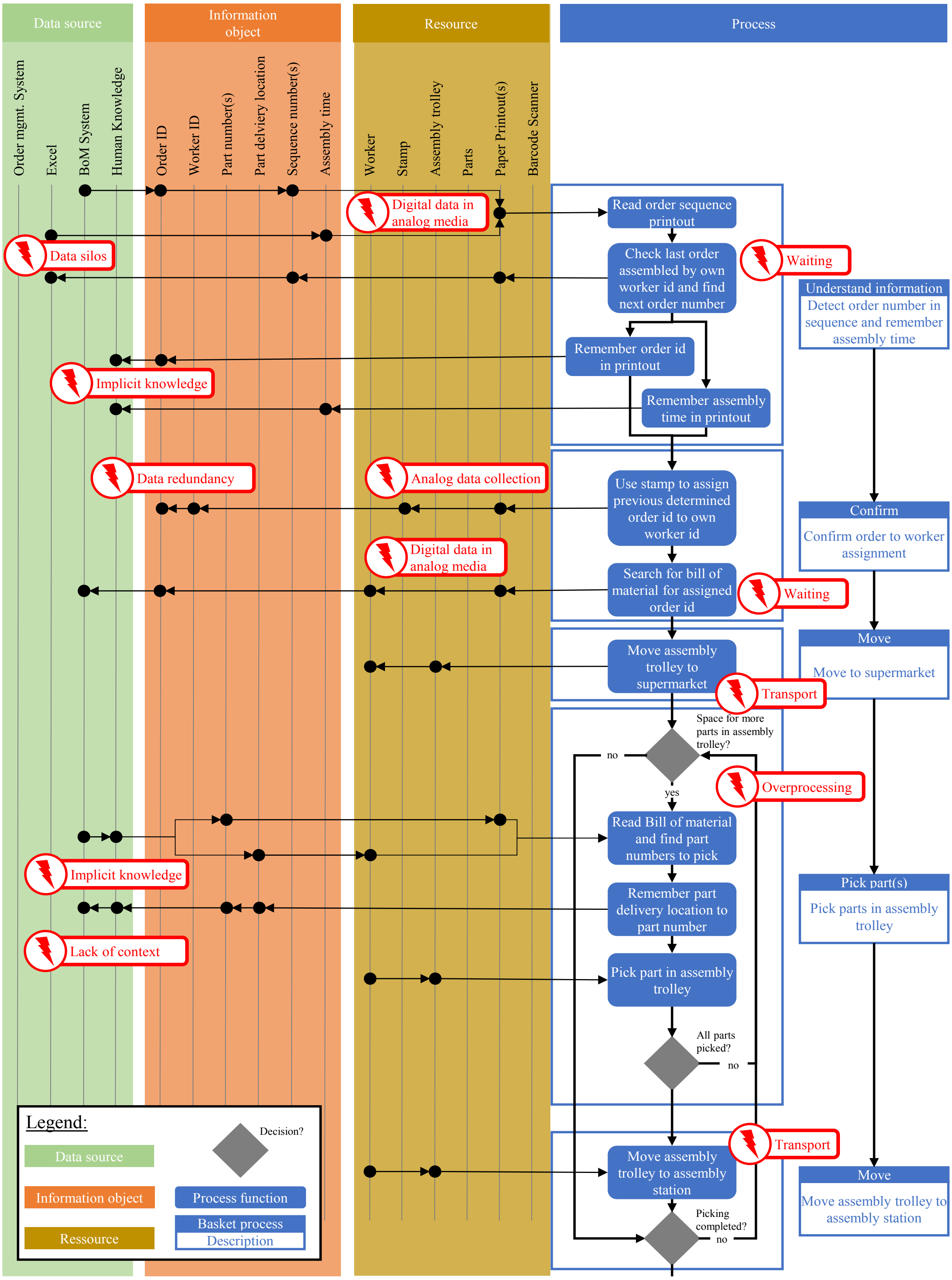

Figure 3: Extract of a MAM-Chart from a pre-assembly station

4.4 Final remarks and conclusion

In comparison, processes at the use case company have typically been analysed using conventional Gemba walks. In contrast to the current method, our approach considerably accelerates the identification of wastage by integrating information flows and physical actions at different aggregation layers through the MAM-

Chart. This proves especially advantageous given the complex and intertwined information and process flows involved in the simultaneous manufacturing of numerous product variants within the same facility.

Conventional process mappings have struggled to systematically capture wastage between handovers of various entities, particularly at the interface between physical and digital domains. Furthermore, the 3M-Chart fosters a systematic approach in regards of identifying adequate countermeasures.

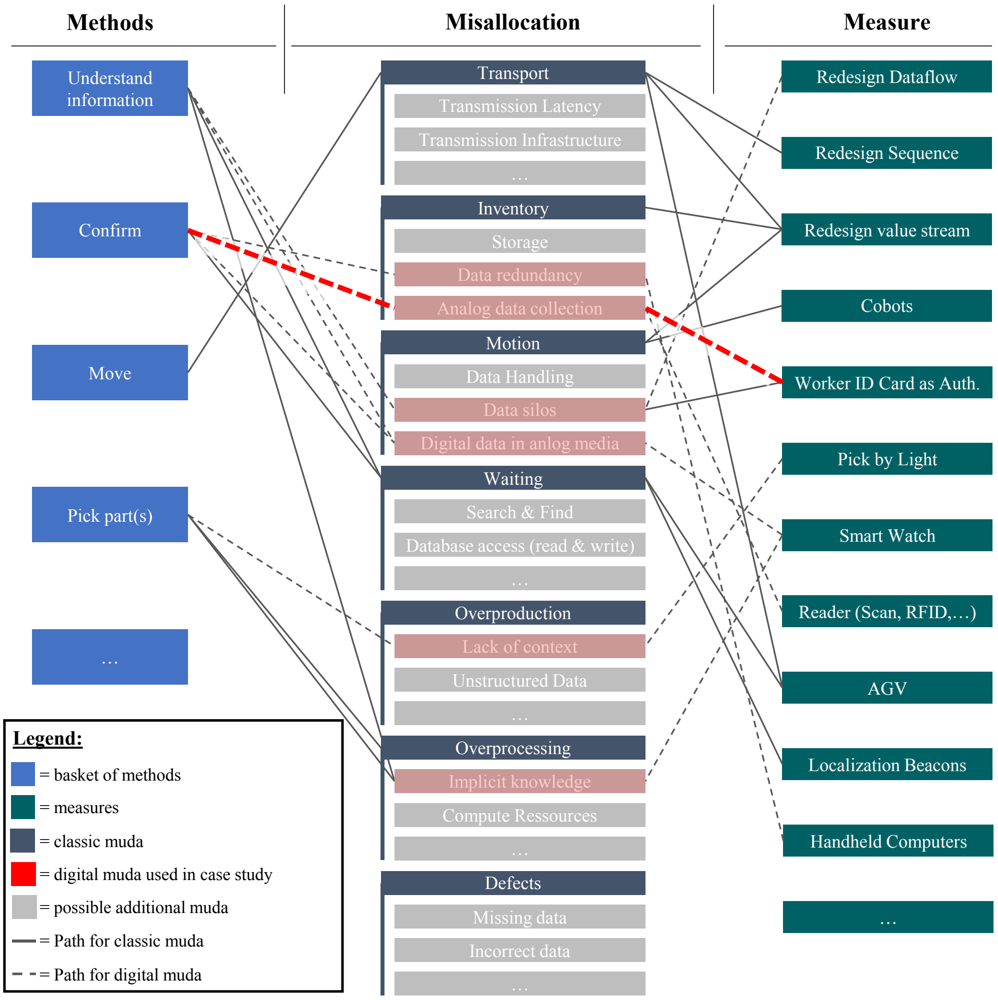

Figure 4: Excerpt of a 3M-Graph

5. Limitations and outlook

This article focuses on the presentation of a generic, applicable approach for reducing both, classic and digital wastage in assembly processes through measures aimed towards digitization. For this purpose, basic modules from a process basket (see Figure 2) are used for the process descriptions, which are then transferred into a more concrete process description using an AD. Subsequently, the wastages found are assigned to measures from the 3M-Graph (see Figure 4). Both, the process basket, and the 3M-Graph were only compiled initially. A completion is therefore not yet given. This requires the analysis of further processes, which will successively contribute to an extension of the basket and the 3M graph. Currently, the presented approach is oriented towards assembly processes. The representation considers the process itself as well as associated resources on the shop floor. However, the product to be manufactured is not taken into account. By additionally considering the product, the procedure could be further refined, e.g., to link a digital representation of the product itself or related information into a fully digital model. This would allow further (classical and digital) wastages in the processes to be modelled accordingly. To further optimize the procedure, it seems sensible to extend the approach to include digitization KPIs. The KPIs mentioned in

METTERNICH ET AL. [11] provide orientation for this. The KPIs presented therein can be used to record the proportion of digitized data in a process, the availability of information and the use of information. However, these metrics should be expanded to include metrics that take wastage into account to ensure that digitization in processes is also done purposefully and does not just prioritize the use of modern technologies. Finally, the measures from the 3M-Graph should be correlated with the efforts necessary. This should consider that the efforts for digitization do not exceed the expected benefit of digitization. Such an assessment cannot be provided in a generic way in the form of catalogues. However, it does seem possible and feasible to derive a procedure for determining the costs, both technically and economically.

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Biography

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