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Lean Engineering – Identifying muda in engineering chains

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Abstract

Data and information in production systems engineering are the counterpart to material in production. To increase effectiveness and efficiency, waste in data and information flow must be defined in analogy to lean paradigm. For this purpose, the known eight types of waste are transferred to the data and information flow of production systems engineering, considering engineering activities and chain, to achieve overall process optimum. The validation of the defined types of waste using six case studies confirms their applicability and significance in terms of continuous engineering process improvement.

Keywords: Production System Engineering; Lean Engineering; Waste; Data and Information flow

1. Introduction

For production systems engineering (engineering), data and information are the equivalent of materials in production. Engineering shapes the production system based on data and information flow with the help of methods and tools. The engineering of the production system is integrated in the overall value stream between product design and serial production. The data and information flow passes through multiple engineering activities. The interaction of these is referred to as the engineering chain. [1]

Engineering decisions can be seen as the value adding activity within the engineering process [2], whose effectiveness and efficiency depends on the logistical principle of information: the right information, at the right time, in the right quantity, at the right place, in the right quality [3] and the selection of relevant information in information overload [4]. The problem that arises is that decision-relevant information in engineering activity and chain is not available effectively and efficiently.

In production system use, efficiency and effectivity can be improved by lean management [5]. Facing the structural similarities of production systems engineering and use, this study focuses on the transfer of the lean viewpoint of waste from production systems use to the data and information flow in engineering activities and chain following a process-oriented overall optimum.

Derived from evidence-based five why method [5] (Table 1), this paper's central research question is: How can waste in information flow in engineering activity and chain be defined, classified and identified according to lean thinking to support effectivity and efficiency of engineering decisions?

Table 1. Evidence-based analysis of root cause.

Problem	Decision-relevant data and information in engineering activity and chain is not available effectively and efficiently.
Why	Because data and information flow in engineering activity and chain is not effective and efficient.
Why	Because data and information flow in engineering activity and chain contains waste.
Why	Because the waste in engineering activity and chain has not been analyzed and eliminated.
Why	Because it is not understood how to eliminate waste in data and information flow of engineering activity and chain.
Root Cause	Because it is not standardized how waste is defined in data and information flow of engineering activity and chain.

To address this research question, a generic model is presented as a basis for the analysis of data and information flows and waste is transferred to the engineering process. The validation is done with the use of case studies.

The paper is structured as follows: Section 2 provides an overview of the theoretical background. Section 3 elaborates on the investigation aspects based on the research question and section 4 raises the research methodology. Section 5 presents the research results validated by case studies. Section 6 discusses the results and limitations and section 7 concludes with an outlook on future work.

2. Theoretical Background

2.1. Information flow in Engineering activity and chain

Engineering of production systems is a multi-disciplinary engineering process executed by engineering organizations, established by engineers utilizing knowledge, skills, tools, and data [1]. This process involves several engineering disciplines developing engineering artifacts required to represent the complex network of products, production processes, and production system resources [6]. Each engineering discipline is executing engineering activities, each containing three main parts: Preprocessing of incoming data from predecessor activities to ensure all necessary information, execution of the engineering decisions, and postprocessing of created information to be able to send data to successor activities (Figure 1) [7].

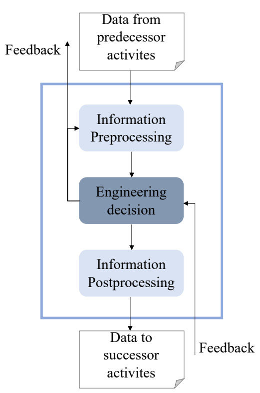

Figure 1. Engineering activity, based on [7].

The sequence and interaction of these engineering activities results in the integrated and overall engineering chain, starting from process planning up to virtual commissioning [1].

Engineering artifacts are based on the processing of data and information through the use of individual knowledge in the decision-making process.

Data are syntactic entities, input to interpretation processes and become information as interpreted data within contextual, semantic relations. Knowledge results from individual interpretation of information, experience and learning processes [8]. An explicit distinction between data and information is case-specific and must be considered in more detail if necessary.

Processing of data and information takes place in any manual or automated activity or activity chain carried out in their context [9], where the activities can be assigned to the life cycle of data and information (Table 2) [10], [11].

Table 2. Data processing, based on [10], [11].

Planning	Matching of data and information needs, supply and demand.
Sourcing	Generate, create, survey new or retrieve existing data and information.
Structuring and storing	Organize, arrange, store, format, transform, normalize, generalize, versioning, in data and information management.
Administration	Restrict, authorize access to data and information for users or user groups (Authorization concept and data security).
Use and refinement	Adapt, modify, evaluate, process, prepare, abstract, analyze, utilize, use, match, link to draw insights from data and information.
Distribution	Pull of data by reading, retrieving or transmitting through push.
Actualization	Maintain, update actuality or utility of data and information.
Disposal	Erase, delete of non-value adding data and information.

2.2. Lean in engineering

Lean is known for the paradigm of “Doing the right things right, first time around.” [5] and addresses the effectiveness and efficiency of activities and processes.

Effectiveness focuses on the achievement of a goal, whereas efficiency considers the path to the goal [12]. Lean follows a systems approach, starting from the specification of customer value, identifying the value stream, creating flow and pull of value towards continuous improvement through the elimination of waste [13].

Waste, or muda in Japanese, means “to toil” or “pointless effort”, has an immediate impact on effectiveness and efficiency and includes all activities that do not benefit the customer. It is found in overproduction, inventory, overprocessing, transport, waiting, movement/motion, defects, and unused intellect/skills in production [5] [12] [14].

Lean admin, also known as lean office, focuses on information and information flow and considers waste in the indirect area, such as engineering, in overinformation and overproduction, waiting and searching, information transfer, complicated workflows, inventory and backlogs, movement, failures and rework, unused information and skills [12].

There are several efforts to sharpen waste in the context of data and information flow.

Meudt et al. apply the lean concept focusing on information logistics in production and the purpose of decision support with eight types of waste: data selection, data quality, process of data collection, data transfer, inventory and waiting, movement and transport and searching, data analysis, decision making [15].

"Digital Muda" is discussed as a new type of waste and defined as uncollected, (partially) unprocessed or misinterpreted data in the context of decision making in the production process [16].

Hicks defines waste in information management as "the additional actions and any inactivity that arise as a consequence of not providing the information consumer immediate access to an adequate amount of appropriate, accurate and up-to-date information." [17].

Nevertheless, all these differentiations can be assigned to the original eight types of waste, in particular focusing lean admin.

3. Investigation Aspect

Following the central research question, it is to define and identify waste in the flow of data and information of an engineering activity and in their interaction. For the investigation of the research question two aspects have to be considered.

First it is to describe: How can data and information flow in engineering activities and chain be concretized to enable a systematic approach and standardize the analysis of waste?

Value stream mapping is an established method in the production environment, whereby an object is accompanied by the value stream. Makigami, also known as swim lanes, considers the requirements of the indirect area in process analysis. [12]

To follow immaterial data and information, a process-oriented, cross-functional generic model (Figure 2) based on the relevant steps of data processing for the analysis of today's process demonstrates the detailed flow in an engineering activity and their connection. After receiving data, a first screening or analysis takes place. In the next step, these need to be evaluated based on specific quality criteria and stored in accordance to the specific use case. Data use and refinement contains all process steps to derive usable information from the data and to prepare the engineering decision. After this, data and information are stored in a final version. Thereby iteration loops to each previous process step are conceivable. The linking of engineering activities is achieved through the exchange of data and information.

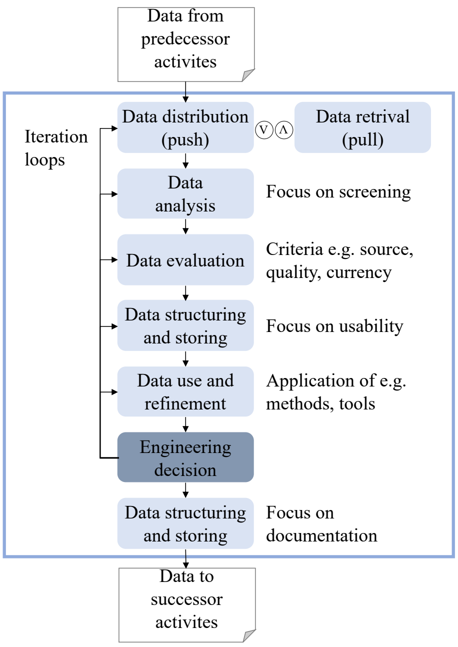

Figure 2. Data processing in engineering activity.

Second, it is necessary to concretize: How to interpret the eight types of waste in engineering activities and chain considering their specific requirements? For this, the eight types of waste are transferred considering the literature study and related works (Table 3).

Table 3. Waste in Lean Engineering.

W1	Mis-information	Waste can be found in quantity (too much, too little), as well as in qualitatively insufficient data or information for the specific purpose or any combination of these as well as in the process of data collection. Data selection not oriented to the customer's needs triggers all other types of waste.
W2	Waiting time and searching	Waiting for data, information, processes, decisions, software tools, devices or colleagues, and search efforts are waste.
W3	Data and information transfer	Data transfer involves the exchange of data between one or more data sources and sinks and does not add value. Misinformation or failures can arise from the type of data transfer (manual or automated) or the conversion of data.
W4	Mismatch in workflow	A workflow is based on a chronological sequence of different activities. If these processes are unclear or difficult to handle, there is a potential for waste.
W5	Inventory and backlogs	Data sets that are not collected and stored in a specific context or for a specific (analysis) purpose are waste. In the processing of data and information, waste arises in work that has not been done or has been done incompletely.
W6	Over-processing	An activity that does not include value creation for the customer is considered as waste.
W7	Failures and rework	The generation and use of incorrect data and information or misinterpretation leads to incorrect results that must be corrected by the use of additional resources.
W8	Skills and potential	Non-utilization of talent as well as, a lack of leadership or qualification is seen as waste. In a figurative sense, the unused potential from data and information also represents waste.

Table 3 identifies the eight types of waste (W) in terms of data and information flow in engineering activities and chain. Misinformation (W1) as counterpart to overproduction addresses the specifics of data and information in terms of quantity and quality in data selection and collection, whereby the orientation to customer needs is seen as a key factor. Waiting time and searching (W2) arises in terms of information exchange or due to performance of devices and software. Interfaces, media disruption, a-synchronous processes, no data consistency leads to waste in data transfers (W3). In contrary to the lean admin approach, movement is seen as a negligible waste in the data and information flow and can be assigned to mismatch in workflows (W4). Inventories and backlogs (W5) arise when, e. g. deletion cycles are not practiced as well as in the form of unprocessed activities. Overengineering (W6) in data and information flow can result e. g. from the use of complex algorithms for simple tasks. Failures and rework (W7) result e. g. from missing standards, outdated information, or even misinterpretation of data. Beyond the original types of waste, the non-utilization of talent is established as a type of waste, whereby this can also result from missing transparency. If data and information are not analyzed or used as a base for decision-making, this is also a source of waste (W8).

4. Methodology

To address the research question and the detailed investigation aspects, the study is based on the Design Science Method [18] and employs selected case studies (step 1). These studies are dedicated to investigate real world aspects. The selection of representative case studies is based on the value chain in the production systems engineering [1] with the purpose of covering a comprehensive range of activities.

This research methodology is used to confirm the generic model of data processing in engineering and its usefulness in the analysis of data and information flow (step 2). After confirming, the current process is mapped in the generic model (step 3). In addition, the defined types of waste for engineering are validated and substantiated with examples (step 4). Ineffectiveness, inefficiency and fields of action are identified (step 5 and 6). The methodical approach concludes with a qualitative evaluation of optimization potential in terms of time, quality and costs (step 7).

5. Use Case descriptions and results

In the following, six use cases and their results are presented in relation to the research question and investigation aspects.

The standardized documentation and validation of the case studies is conducted by a brief description, the selection up to three identified main types of waste as well as the associated root cause, starting points and potentials.

5.1. Project planning in strategic development system

The described planning scenario is the project-specific vehicle planning in production systems engineering and focuses on the interaction of specific activities in the engineering chain. More precisely, it is about the entry of schedules following a strategic development system. This is done across departments and IT systems. The current schedules of the vehicle projects are entered into existing IT systems and detailed. The existing information is entered manually by several participants into respective IT systems required. However, there is potential for improvement by means of this transfer. One potential is found in the transfer of data and information (W3). However, the waiting time (W2) that arises during manual transfer must not be disregarded. Since the data being handled is classified as secret, the challenge is to create an interface using appropriate security measures. This can lead to some process improvements. On the one hand, an automation of the process steps is simplified, and on the other hand, a single source of truth can be achieved. Furthermore, additional work steps such as manual reconciliation between the systems are no longer needed. The transfer of data and information (W3) is also seen as a challenge with regard to the points of analysis, structuring and engineering decisions in relation to a structured analysis of the data. In order to make data-driven decisions faster and more efficiently, data and information must be processed automatically. Thus, decisions can be made more consistently. Difficulties with short-term changes in deadlines would also be recognized and solved more quickly.

5.2. Mechanical Engineering (3D Design)

This use case is concerning the 3D design process. The company's internal standardized and transparent workflow starts with the reception of design relevant data. This is followed by manual checking, classification and 3D design. Finally, the newly generated data is evaluated and available for the subsequent processes.

In this process unused skills and potential (W8) in manual data checking was identified as the most common type of waste. Due to the increasing requirements and the resulting challenges in projects, it is necessary to further evolve existing skills and tools of employees. Delays in this process can result in misinterpretations of complex processes, so that incorrect decisions can occur due to subjective impressions. Further training and optimized tools in the engineering process can be used as a starting point for improvement. This can increase efficiency and effectiveness and optimize the data basis for downstream process steps.

Misinformation (W1) is the second most common type of waste in the analysed use case. In a very early project phase, often only limited information is available, which can lead to misinformation. A central data management system that automatically issues a processing release at the time when the required data is fully available or requests missing information could be a possible improvement. This offers a huge potential for an optimized information exchange.

The third most common waste is waiting time and searching (W2) during concept evaluation of the design. Wating times occur due to the availability of responsible employees, which are working on several projects at the same time, to approve the elaborated design. A general release management could support increasing the availability of necessary employees, i.e., through push notifications and status tracking in a central data management system. This can result in significant time savings and speed up order processes. Optimized engineering processes generate high market potential and can ensure future competitiveness.

5.3. Process planning of material provisioning in assembly

In the scenario, an interdisciplinary topic between assembly and logistics is examined. Logistics planning creates a material layout in its planning tool. This data is shared with the assembly from the logistics system. The assembly planning reviews the data and manually inserts it into the assembly system. In the following, it is verified on the assembly side whether the logistics planning is compatible with the assembly planning. Based on this, feedback can be sent to logistics as to whether the planning needs to be reworked or can remain as it is. The data in the assembly system can then be used for further processes or processed. The *main types of waste* are data and information transfer (W3) and mismatch in workflow (W4). Starting with W3 the *route cause* is the missing data consistency. In this process the employees have to work in two independent systems with the same data, because different departments have different systems. *Starting point* can be an approach of single source of truth. There must be agreement on working in one system to prevent the extra work. The *potential* is a reduction in manual labor and associated personnel costs. *Route cause* to the second main type of waste (W4) is the lack of synchronous process flows. The departments can be commissioned separately for one project, so that the interfaces that arise in the projects are different and not clearly defined. The *starting point* here is organizational. There must be a uniform assignment and clarity about the scope and responsibilities between the departments. With the help of this measure, the time required within the project and these planning scenarios should be reduced, and in the course of this also the personnel costs.

5.4. FMEA based quality management

Another considered planning scenario is the FMEA (failure modes & effects analysis) based design of a user centric quality support system as presented in [19]. It is based on the combination of FMEA models with PPR (Product, Process, Resource) based models of a production system to enable the identification of causes for production process quality limitations. Within this process a PPR model needs to be received from a process engineering tool, to be extended by additional resource data from detail engineering (down to automation devices), combined with FMEA models, and finally used to identify detailed resources (automation devices) being potential roots for negative quality effects presented in the FMEA models.

The identified *main types of waste* are misinformation (W1), overprocessing (W6) and searching (W2). The main *root causes* for these wastes are incomplete input data (in case of misinformation, that can be counteracted by sensitizing the model providing engineers for data completeness), improper selection of data structures (in case of overprocessing, that can be counteracted by a proper consideration of asset models relevant within the different engineering disciplines), and improper structured data sources (in case of searching, that can be counteracted by establishing a proper team workspace).

One special finding in this scenario is the possibility of propagation of overprocessing related waste over (semi-) automated engineering activities. This is found in our scenario within the sequence of data analysis and evaluation, data structuring and storing and data use and refinement that is based on the utilization of automatic model transformation, integration and selection based on AutomationML data models as discussed in [20].

Key learnings are the existence and potential propagation of overprocessing and the importance of proper discipline crossing information modelling for waste reduction.

5.5. Model generation for virtual commissioning of production plants

Another *planning scenario* is the virtual commissioning (VC) of production plants, which mostly represents one of the final steps in the planning process. In the following, the model generation for VC is examined. For this, the artifacts created during the planning process are combined to form an overall model as described in [21], supplemented with behavioral models and test data and enabled to carry out VC with the help of dedicated tools. The details of the VC can be found in [22].

The main types of waste in this use case are (W7) failures and rework, (W1) misinformation and data and information transfer (W3). When analyzing the data, there are often inconsistencies, which means that the artifacts cannot be seamlessly linked into an overall model. Mostly the data needs to be manually reprocessed, which is a classic example of waste (W7). The root cause is insufficient compliance with standards or the lack of appropriate standards.

In addition, when analyzing the data, it is often noticed that the artifacts are incomplete or are available in the wrong format. This type of waste (W1) is caused by a lack of awareness in previous steps about the VC requirements, missing interfaces, or unsuitable data formats.

As already mentioned above, VC requires data and artifacts to be collected from various process steps and therefore from several planning tools. This collection is characterized by a lot of manual effort and searching, which is clearly a form of waste (W3). The main reason for this waste is a lack of data consistency, inadequate compliance with standards, data breaches and a lack of interfaces. The starting point for eliminating all the above types of waste in this use case is to adapt the interfaces or better to implement a data hub so that the appropriate data can be automatically exported in the specified standard and is accessible at a central location. By eliminating these types of waste, enormous potential for saving time and increasing data quality can be realized.

The central findings from this use case are critical need for the implementation of a data hub as a single point of access for all relevant planning data as well as the binding definition of standards and compliance with them.

5.6. Reengineering: Dark data in manufacturing

A further *planning scenario* is the „Data analysis of dark data in manufacturing" and the need for reengineering. The background of this scenario is an initial engineering of measuring equipment for a machine. The required product quality is verified using this measuring equipment at defined points in the production process. The process-information results in the form of an Andon-board. The provided process-information proved to be insufficient during the ongoing manufacturing process, which lead to a reengineering. The identified *main types of waste* are misinformation (W1), inventory and backlogs (W5), as well as skills and potential

(W8). The main *root cause* is attributable to the initial requirements management and the identification of relevant stakeholders. Specifically, it was determined that more data points than necessary were obtained during the initial engineering process. This offers additional potential for further data analysis, but leads to misinformation (W1) in the first step and subsequently to inventory (W5).

Additionally, the resulting data structure was created by non-IT professionals due to a lack of stakeholder analysis. This leads to an unrefined engineering decision and data structuring and storing, as the *starting point* in the initial engineering (W8). The crucial potential avoiding a reengineering thus results in *quality*. In the future, a more profound, demand-oriented process information extraction is to be optimized by modifying the requirements management.

6. Discussion and Limitation

The usability and benefit of the generic analysis model (Figure 2) was confirmed in all of the case studies, whereby it is required to further elaborate the applicability for engineering chains. The defined eight types of waste (W1 - W8) were identified several times and rated as relevant by the domain experts, with misinformation (W1), data and information transfer (W3) and digital literacy (W8) highlighted. The validity of the defined types of waste for data and information flow in engineering activity and chain (Table 3) can be confirmed for the selected case studies.

A correlation between data push and pull in relation to misinformation (W1) is assumed, which needs further investigation. It cannot be excluded that various engineering activities and chains cannot be considered in analogy to the selected case studies. The applicability has to be evaluated in an end-to-end engineering scenario.

7. Conclusion and Outlook

Data and information flows form the basis for value creation in engineering and are characterized by effectiveness and efficiency losses in today's process. Based on a generic model for process analysis (Figure 2) and the definition of waste in the data and information flow of engineering activities and chain (Table 3), waste can be identified precisely and reproducibly as a starting point for optimization. In which all activities of the life cycle of data and information should be considered (Table 2).

The methodology and definition of waste will be transferred to a further research project in order to advance its generalizability and standardization. The waste types misinformation resulting from an insufficient demand orientation as well as missing digital competence will also be investigated.

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