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MDM AS A PROCESS MAPPING TOOL IN LEAN CONSTRUCTION

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1 INTRODUCTION

Lean thinking strives for the elimination of waste at any point in a product's progress from development to production to delivery (Womack & Jones 2003). Lean construction applies the principles of lean thinking, such as value and waste, to the delivery process (design and construction) to the AEC (Architecture Engineering Construction) industry. Since construction is essentially an extensive product development process (Ballard & Howell 1994), lean construction shifts from a production view to an integrated view on all phases of the delivery process. Thus, construction processes have to be designed and planned in detail to enable construction without delays. This requires that processes are designed correctly in the first place, instead of examined and modified during execution. A significant challenge is that processes are often branched and complex. In order to establish a realistic picture of the process, process mapping tools need to capture the interconnectedness of a process' steps.

This paper discusses the topic of mapping processes in lean construction and illustrates the application of the Multi-Domain Matrix (MDM) as a process mapping tool using the example of a plumbing installation process design. The objective of the MDM application is to facilitate process mapping through deduction of dependencies and to provide conclusions for future state map generation based on analysis of the process' underlying structure.

2 MOTIVATION

Complexity of processes (or value streams) has effects on waste and value within the process. Currently, complexity is a less regarded issue in lean thinking. From a lean thinking point of view, complexity is neither waste nor value per se, but it is a system's characteristic leading to and resulting from waste or value. Sole elimination of complexity cannot be a valid strategy since complexity can relate to value. Thus, complexity management in lean thinking needs to distinguish complexity linked to value from complexity linked to waste. It should focus on the active management of complexity linked to value and the elimination of complexity linked to waste.

Value stream mapping (VSM) complex processes can help to manage complexity, but most current tools are not practical for depicting the branched and iterative nature of a complex process. This is because VSM illustrates the flow of a product and highlights wasteful steps but does not aim at capturing complexity. Several process mapping tools, e.g., cross-functional process mapping (Damelio 1996), offer the capability to capture complex processes that form a network of processes, but most tools do not aim at capturing the branched nature of value streams in one map but require multiple ones (Rother & Shook 1998, König et al. 2008, McManus 2005, Millard 2001). As processes and their tasks are highly dependent on each other, capturing the underlying structure of the overall process right away is difficult. A separate analysis of multiple maps is impractical as tasks are highly interconnected.

Further, current tools do not regard complexity as an attribute of a process that arises from the process' underlying structure and structural characteristics (Lindemann et al. 2009). However, the development of a future state map, required to enhance the efficiency of a process, implies a sound understanding of the process' underlying structure. Nevertheless, missing knowledge of dependencies constrains effective future state map generation. However, in-depth analysis of this structure calls for a tool capable of illustrating the process' structure.

3 APPROACH

Capturing processes by drawing arrows and boxes in a graphical representation creates difficulties for the users to indentify whether all possible dependencies have been considered (Lindemann et al. 2009). Consequently, mapping complex and interconnected processes with conventional tools can be rather difficult. Sound future state map generation requires an extension of current process mapping and VSM tools that provides dependencies deduction between process steps and supports structure analysis. Deduction of the dependencies by means of Multi-Domain Matrix (MDM) and Design Structure Matrix (DSM) provides systematic access to all dependencies and makes the underlying structure accessible.

The challenge is to map the process accurately in a DSM because it is difficult to capture all existing dependencies. Accordingly, the DSM cannot be directly acquired in an accurate state. Therefore, the application of the MDM as process mapping tool is proposed because it supports the deduction of dependencies. Analysis of the deduced DSM advances the understanding of the current state process and consequently provides a sound basis for future state development. In addition, the application of the MDM ensures systematic information acquisition and facilitates the analysis of the underlying structure (Lindemann et al. 2009).

3.1 Modelling Method

Exposing all dependencies between the process steps accurately is a key difficulty in mapping complex processes. Deubzer and Lindemann (2008) illustrate an application of the MDM for functional modelling (Ehrlenspiel 2003). Two Domain Mapping Matrices (DMMs) represent the links between operations and states, and vice versa. According to the deduction logics presented by Maurer (2007), the dependencies between operations or states can be derived. This modelling approach can be adapted to process mapping because process steps are connected to their inputs and outputs in a similar way. In production processes these inputs and outputs are usually physical inventories. Since in product development processes information flows (Austin et al. 2000; Browning 2001; Eppinger 2001), inventories usually exist in the form of documents, drawings or databases. Most VSM tools map out inventories (e.g., Rother & Shook 1997, McManus 2005). This simplifies the information acquisition because the information is already at hand.

A project step is a set of actions which accomplish a certain assignment. In both cases mentioned before, a process step transfers the subject of consideration from an input to an output, while changing the subject's attributes. Consequently, input inventories deliver to process steps and process steps deliver to output inventories which are input inventories for the next process steps. The inventories can also be considered as the state of the subject of consideration between two process steps. Hence, the notation is the same as for functional modelling. Consequently, the same logic of deduction derives the dependencies between the tasks. The resulting network of dependencies presents the flow within the tasks. For construction operations, this flow would be a material flow. In product development or lean design processes, this flow would be information flow. *Figure 1* illustrates this approach.

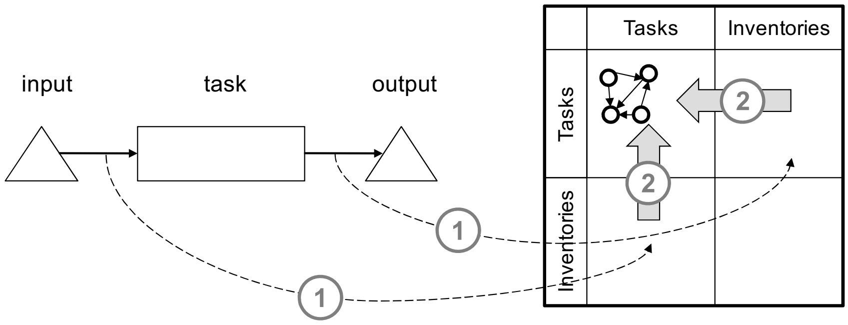

Figure 1. Framework of process modeling

3.2 Structure analysis

Structure analysis comprises the identification of a system's characteristics and the derivation of calls for action by means of the application of algorithms and subsequent interpretation of the results. The identification of characteristics helps to develop a substantial understanding of the system in question. For example, the identification of articulation nodes helps to spot potential bottlenecks in the process. This knowledge makes the system behaviour more predictable and helps to plan the current state of the process accordingly. The derived network of process steps can be visualized as a graph and as a matrix. Analysis of both forms of process' representation expands from focusing on the characterization of the entire structure and its behaviour to a specific focus on the structural embedding of single elements and dependencies. The objective of the MDM application is the identification of the root causes of problems and the conclusion of potentials for the system's optimization. It is important that analysis objectives are planned precisely in order to avoid unnecessary or confusing analysis.. In the case of VSM interpretation of the derived network of tasks, edges represent the process' tasks, nodes illustrate the dependencies between those tasks and subsets are formed by groups of tasks which are closely related. The analysis necessitates suitable analysis criteria for the characterization of the edges and nodes, subsets, and the entire network that allow an interpretation from a VSM point of view. Lindemann et al. (2009) provide basic analysis criteria for the classification of nodes and edges, subsets, and systems. These analysis criteria allow process analysis and therefore just need to be interpreted from a lean thinking point of view. The following case study gives an example for such an interpretation.

4 CASE STUDY: PLUMBING INSTALLATION PROCESS

4.1 Problem description

This subsection represents a use case of the MDM as a process mapping tool. The case applies the MDM to the design of the plumbing installation process in patient rooms of a hospital. A conceptual plumbing installation plan, based on expert knowledge and experience from past projects, was already developed. This plan represents the current state of the process. The knowledge provided by structure analysis can provide the basis for the development of a future state process. The main purpose of the MDM application was to develop a plan to most efficiently deliver plumbing services for the hospital.

In a first step, the process development team laid out the installation tasks for the plumbing system in a cross-functional process map.

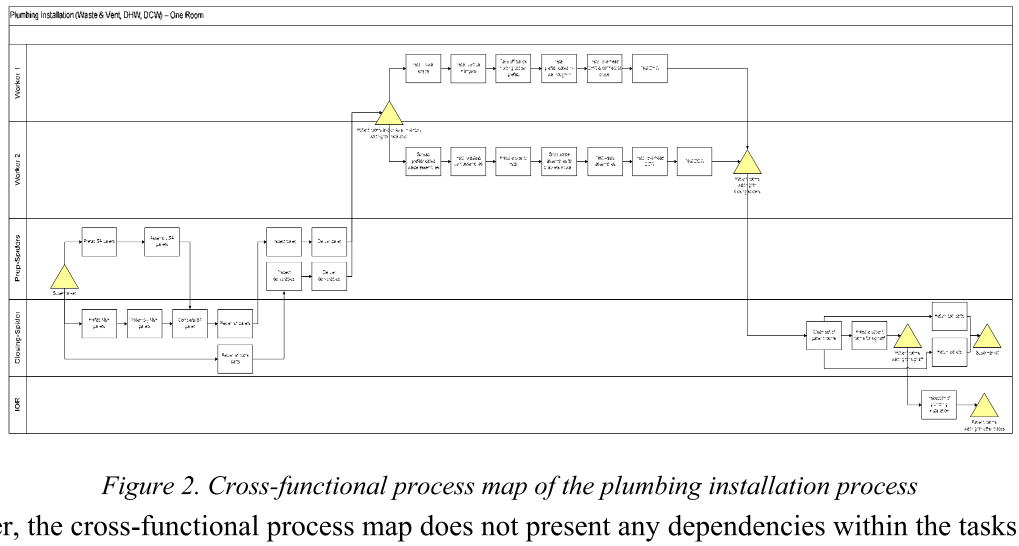

Figure 2. Cross-functional process map of the plumbing installation process

However, the cross-functional process map does not present any dependencies within the tasks. Hence, the flow of material is not illustrated in this process representation. The development of current state representation in a VSM turned out to be difficult because more than one material flow existed. The complexity of dependencies between the material flows made mapping by means of the conventional VSM method (Rother & Shook 1998) impossible. Even if the underlying material flows were visible in the first place, the application of the conventional VSM method would still result in several value streams, a situation which is difficult to capture in a comprehensive VSM representation.

4.2 Application

The cross-functional process map served as a starting point for the acquisition of information to fill the required two native DMMs that connect inventories and tasks. Therefore, information on the tasks was gathered from the cross-functional process map (see Figure 2). Input and output inventories were allocated to the tasks. With the information on hand, the DSM containing the network of tasks can be derived by means of the applicable deduction logic (Lindemann et al. 2009). This DSM was computed from information stored in the two opposite DMMs linking the tasks with the inventories. For further analysis, the resulting DSM was illustrated in graphical representation. Several structural characteristics were identified that can help to improve the current state map. Figure 3 shows the deduced network of tasks and pinpoints structural characteristics which were identified through inspection of the graph.

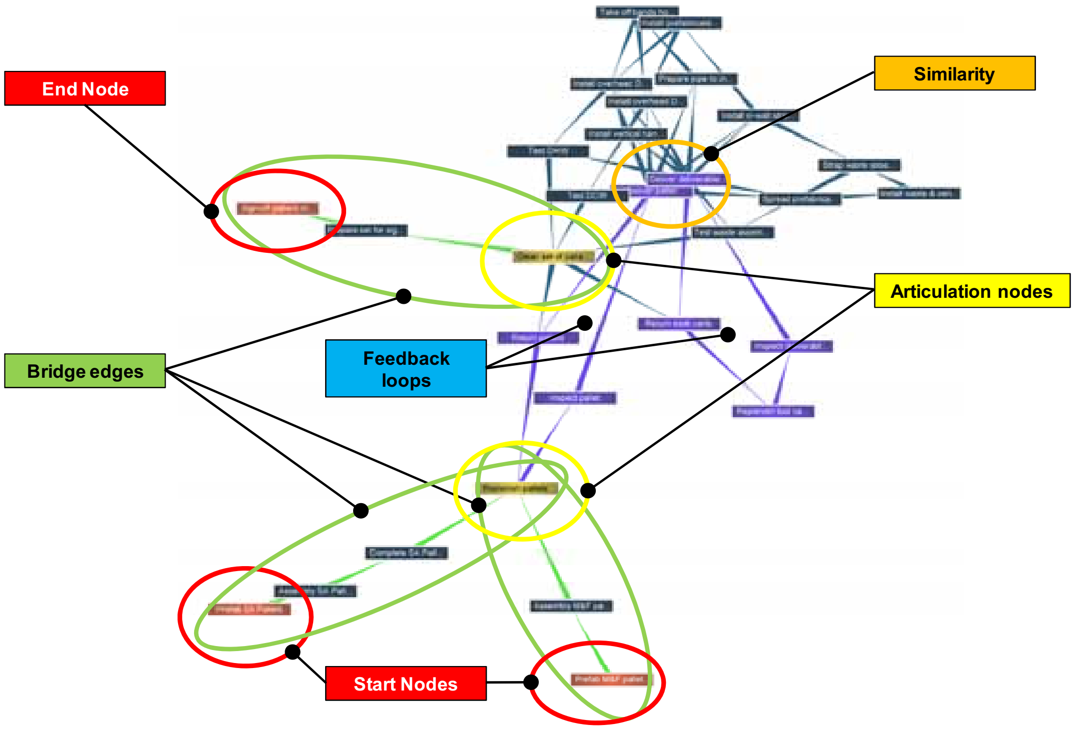

Figure 3. Deduced network

The deduced structure shows a highly interconnected subset and three sequential (bridge edges) paths connecting the subset with the end and start nodes. Articulation nodes connect these paths to the subset in the middle. The sequential paths can be seen as separate processes delivering to the subset, or receiving from the subset. They are connected by articulation nodes which form bottlenecks and therefore can define the processes' takt-time. Further, there are two feedback loops in the structure. In this case, these loops show the opportunity for KANBAN supply of materials. As shown in Figure 3, the left feedback loop pulls material out of the two paths. In addition, the structure shows a similarity. This similarity points out two tasks that can be integrated to one task. As those tasks are both part of the feedback loop, it might be possible to integrate the feedback loops as well. Moreover, the structure shows a hierarchy, beginning at the articulation node and connecting the end node with the subset in the middle. The hierarchy illuminates the material flows converging in an articulation node. As illustrated in Figure 4, three separate material flows can be identified.

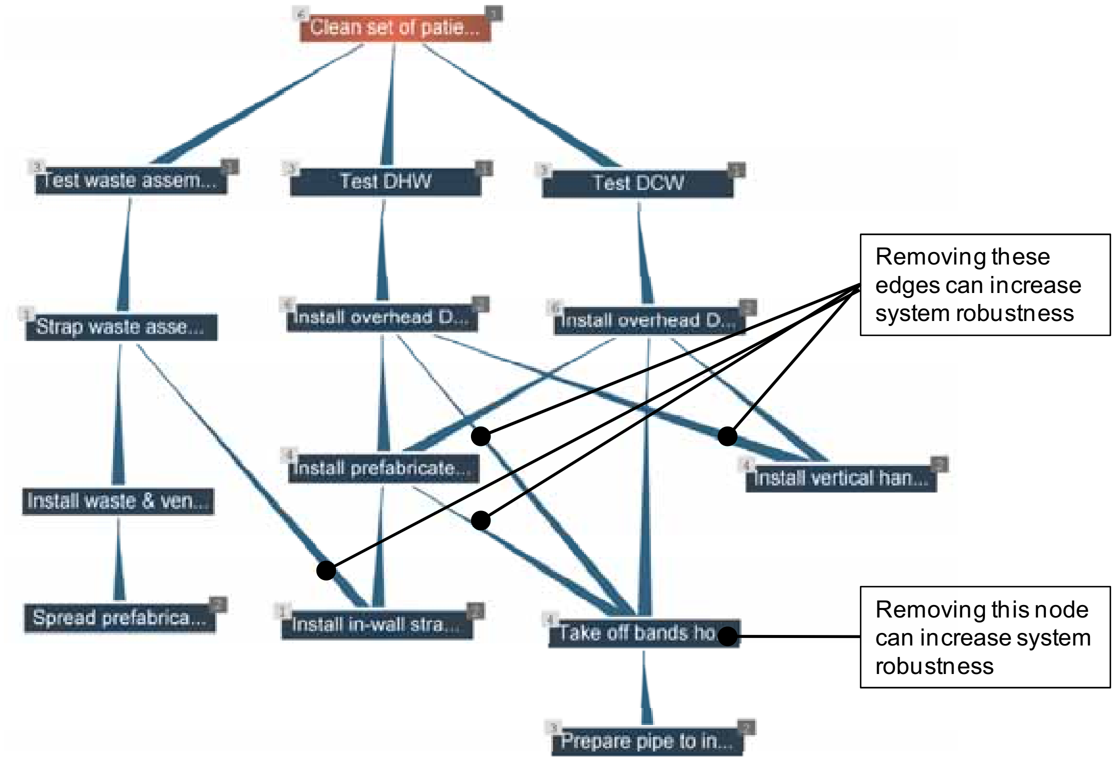

Figure 4. Hierarchy shows three material flows

By removing the edges between these three flows, the installation process' robustness and flexibility can be increased because the three flows no longer depend on each other. Removing edges or nodes can be achieved by rearranging steps or by finding different solution to provide the outcome of the task. In the specific case edges can be included in the prefabrication tasks. Matrix-based approaches such as clustering and triangularization do not provide improvements because the deduced network consists of almost only feed-forward processes.

5. CONCLUSION

The application of the MDM methodology enables the user to map out a process by acquiring information on how the tasks within a process are connected to their respective inputs and outputs (inventories). Hence, a DSM containing the dependencies between the tasks can be derived by means of deduction logic. Structural complexity management provides criteria for the characterization of the process' structure. Analysis of these characteristics leads to suggestions for improvement of the process. The case study showed that these criteria can be interpreted from a lean thinking perspective. This combination of lean thinking principles, such as value and waste, and structural characteristics extends VSM by a more comprehensive understanding of the process and therefore can lead to better process improvement. In example, the hierarchy illustrates different possibility for work structuring which could reduce the projects takt-time to half a day instead of one day. Analysis of feedback loops allowed for an interpretation of iterations and validated the application of KANBAN.

The case shows only a few advantages of the MDM as a process mapping tool. This application extends the MDM as a process modelling tool, as for example proposed by König et al. (2009) in the area of lean thinking. MDM application allows for the identification of complexity deriving from a process' structure. It can support VSM because MDM application enables the deduction of dependencies which helps to fetch a more comprehensive picture of a process than solely drawing a process map. Furthermore, it facilitates process improvements due to the application of structure analysis. Since Tuholski and Tommelein (2009) already successfully applied the DSM to analyse design iteration, the application of the MDM to map out design process seems to be the next promising step. In summary, application of the MDM may offer a means to capture and analyze the branched and complex nature of design processes and consequently should be further investigated.

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- Complexity in Lean Thinking
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MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Why look at complexity?

- Complexity is a less regarded issue in lean thinking
  - Complexity can be wasteful
  - But complexity also required to provide value
- Complexity present in Architecture, Engineering and Construction Industry
  - Managing complexity helps to improve project delivery
  - Similarities between Lean Construction and Lean Product Development, hence application of
- Process Mapping of Construction process during proces design
  - Processes are often branched and complex
  - Realistic picture of process requires capturing interconnectedness of process steps
  - Capturing processes by drawing boxes and arrows rather difficult

Application if structural complexity management for process mapping in the design phase of lean construction

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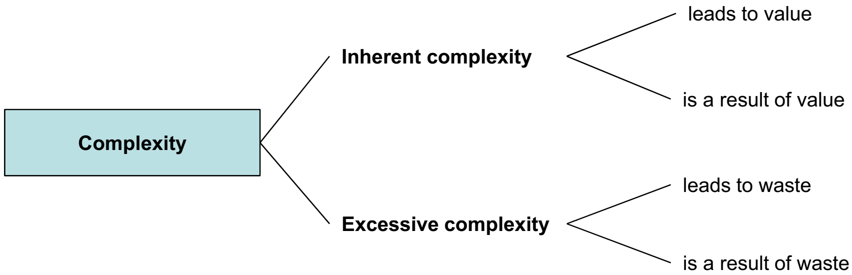
Complexity in Lean Thinking

- Complexity is a process' characteristic leading to and resulting from waste or value
  - Sole elimination of complexity can result in loss of value
  - But excessive complexity relates to waste in the process
- Strategies:
  - Management of complexity linked to value
  - Elimination of complexity linked to waste
- Process Mapping tools do not capture a process' complexity
  - Process tools have difficulties capturing branched and iterative nature of process
  - Large number of dependencies complicates capturing the process right a way



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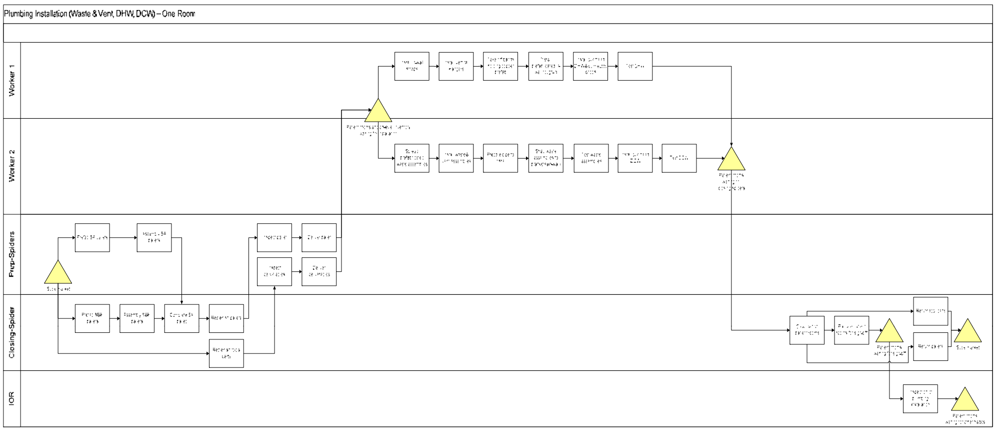
Case Study: Plumbing Installation Process Design

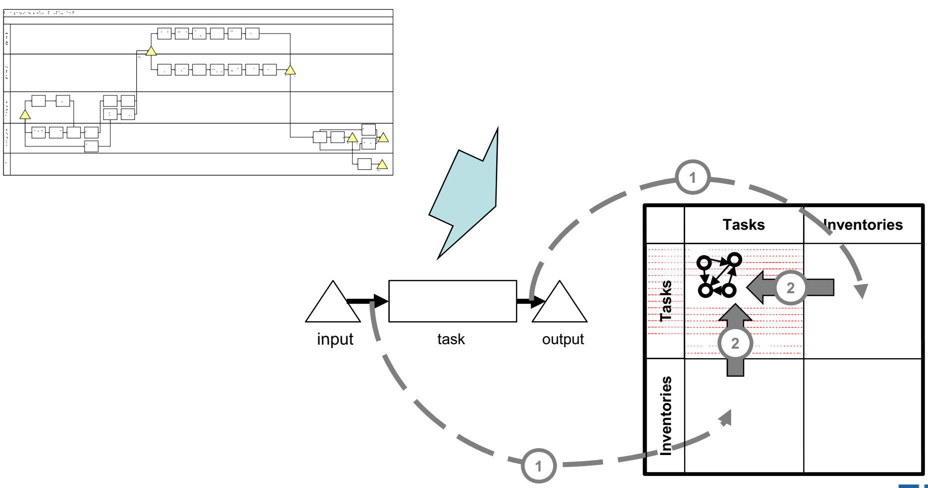
Captured Current State

- The captured swim lane diagram shows only the major inventories (inventories between steps are not included)
- Current State representation in VSM turned out to be difficult because flow was directly definable due to a number of dependencies



Modeling approach

- Instead of acquiring DSM directly, the links between inputs and outputs are acquired in two DMMs (input delivers to task, task delivers to output)
- A DSM showing the tasks dependencies can be derived by means of deduction logics



[adapted from Deubzer & Lindemann 2008]

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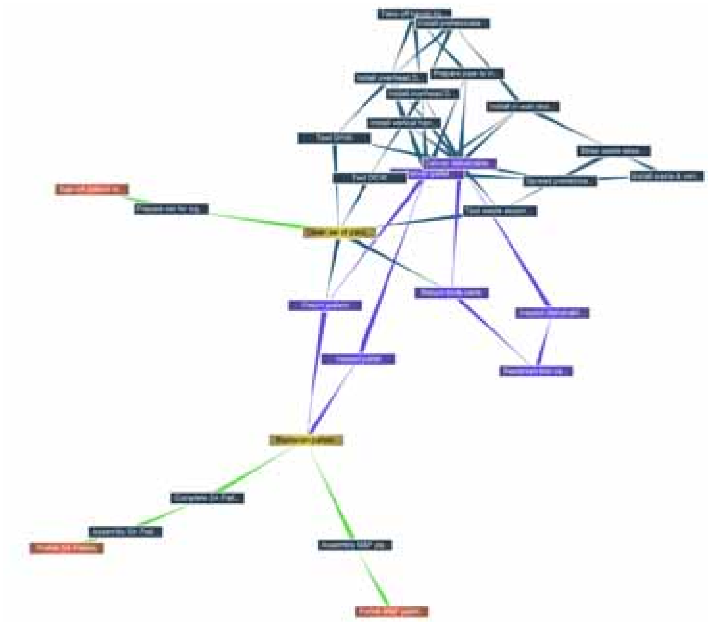
Deduced network



- Deduced network gives a more comprehensive picture than directly captured swim lane diagram
- Identification and analysis of the characteristics of the derived network
- Certain analysis criteria allow for an interpretation from a lean thinking point of view

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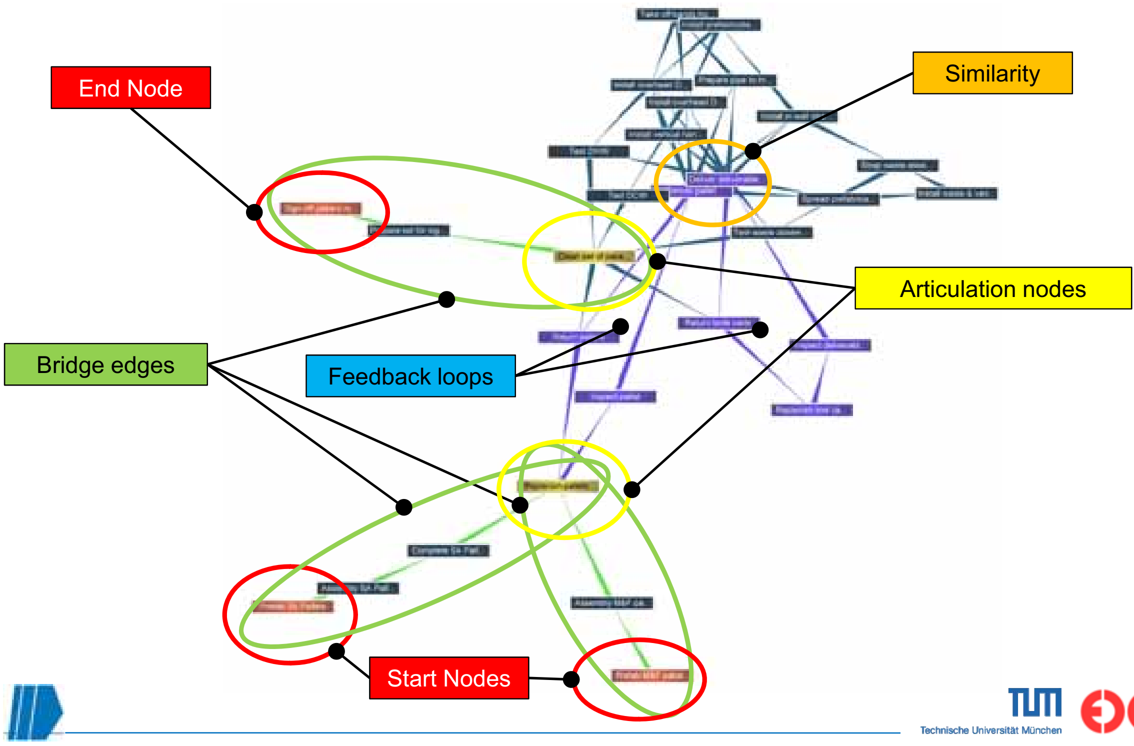
Structure analysis

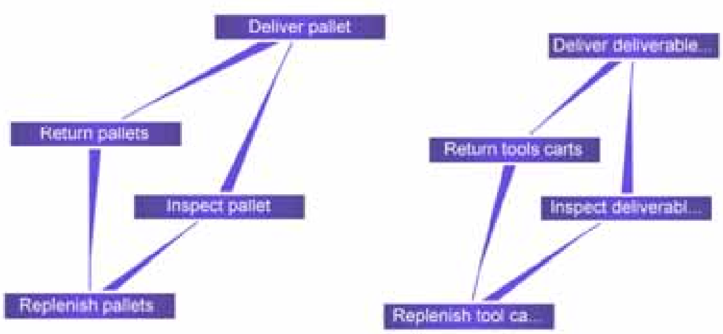
Analysis criteria	Significance	Interpretation from VSM View
Articulation node (single element connecting subsets)	• Forms bottleneck • Decoupling can prevent transfer between two subsets	• Process bottleneck sets takt-time
Bridge edge (single connection between subsets)	• Forms bottleneck • Decoupling can prevent transfer between two subsets	• Process bottleneck sets takt-time
End node, Start node	• Define process input and output • Connection to next system	• Task that releases/receives pull-signal for next trade
Feedback loop	• Iteration	• Regarding material flow: opportunity for KANBAN supply
Hierarchy (Dependency chain from top node over several levels)	• Top level elements induces cascade of change impacts on subsequent elements	• Depicts the flow of material
Similarity (Identical connections of two different nodes to surrounding nodes)	• Nodes posses several successors (predecessors)	• Tasks that can be integrated

Structure analysis



Structure analysis: Feedback loops

- Feedback loops illustrate iteration
- Analysis helps to distinguish between
  - Value adding iterations
  - Wasteful iterations



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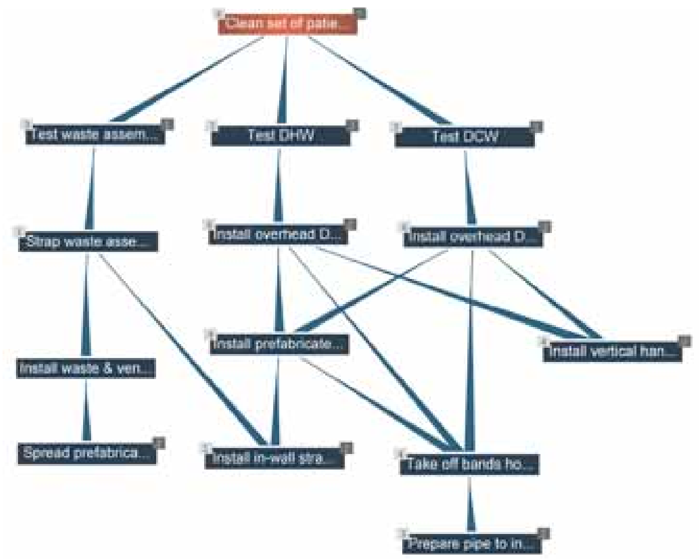
Structure analysis: Hierarchy

- Hierarchy illustrates flow
- Understanding of the flow provides opportunities for restructuring of the process
- Hierarchy shows edges and nodes that link the different value stream
- Removing these edges and nodes can increase process stability



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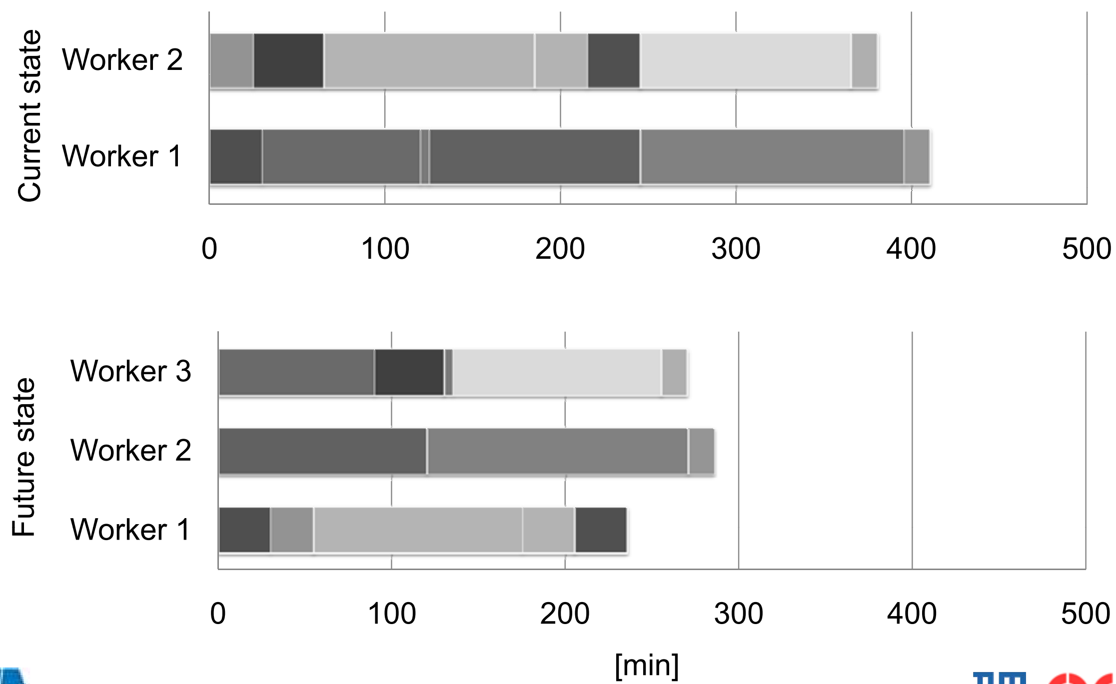
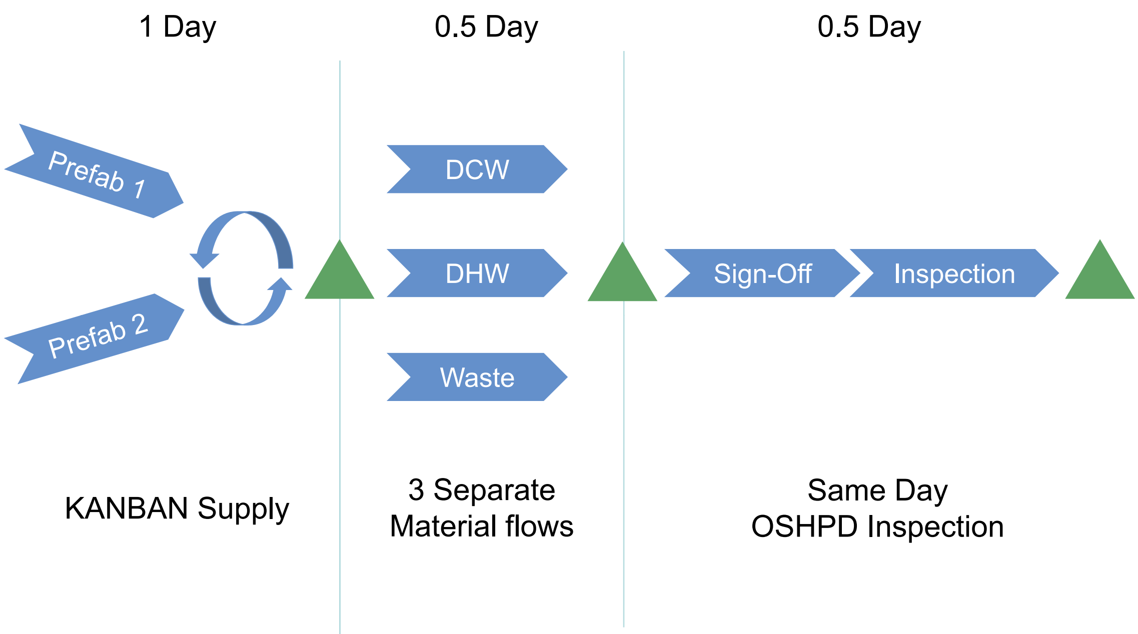
Process bar chart (Current state)



Comparison: Current vs. possible future state

Figures	Current state	Future state
Number of installers	12 workers	12 workers
Number of installed per crew	2 workers per crew	3 workers per crew
Installation duration (per crew and room)	1.0 days	0.5 days
Max. rooms to be installed per day	**6 rooms**	**8 rooms**

Suggestions for future state map



Conclusion

- Case study results
  - Identification of wasteful steps by better interpretation of tasks interconnectedness and structural analysis
  - Analysis of iterations helps to distinguish between value adding (e.g. KANBAN) or wasteful iteration
  - Hierarchy outlines the flow
- MDM application has capability to enhance Value Stream Mapping
  - More detailed and comprehensive picture of the process
  - But not all types of wastes are considered
- Ideas for further research
  - Application to development process
  - Link characteristics to lean thinking
  - Extension of the capabilities of the MDM as a process analysis tool