Procedure (continued)	main formula of work sampling: $$n' = \frac{1{,}96^2 \cdot p' \cdot (100 - p')}{f'^2}$$ where n' number of observations required p' estimated proportion of the most relevant category of activity, in percent of the total process f' desired absolute confidence interval, in percent, with which to determine the respective category of activity 4) **Determine observation intervals** The observation intervals shall be adapted to the specific work processes, i.e. they shall be scaled with sufficient accuracy. For short process cycles, an observation interval of, e.g., few minutes can be specified whereas longer work processes also permit longer observation intervals. Care shall be taken to ensure that each event has the same chance of being sampled. 5) **Perform observations** At the observation location, the observer logs the category of activity (actual condition at a given instant) observed at the instant of the measurement interval. The identified category of activity is documented in the data collection sheet (see Figure A2) by making one tally mark. If, during an observation, the transition from one category of activity to another is encountered, the preceding category shall be logged as a matter of principle. 6) **Final evaluation** The final evaluation includes the compiling and processing of the results (see Figure A3 and Figure A4). Depending on the category of activity, the total number of observations (tally marks) is summed up and the percentage frequency is determined. Findings on process improvement can be obtained from the overall frequency of the categories of activity or their percentage distribution over time. Further data for determining the statistical confidence interval can be determined by means of REFA studies.
Potentials and risks	
Potentials	• no measuring instruments required • suitable for rather large groups (work systems observable at all times) • Workers to be observed are hardly disturbed in their work. • Continuous observation of events is not necessary. • Sampling can be interrupted and resumed. • possibility to observe several work systems • possibility to capture a reliable image of the work process thanks to the rather long duration of the study (several days, mostly several weeks)
Risks	• Performing the study is only permissible if the work process to be observed is non-repetitive, i.e. the work is not performed in strict cycles. • Qualified personnel for planning, conducting, and evaluating the study is required. • Correctness of individual notes cannot retrospectively be verified. • Levels of performance cannot be identified. • Results are actual times that cannot be converted to target times. • only limitedly helpful in designing the workplace and the work process • does not provide information on causes of problems • No statements can be made concerning categories of activity that account for less than 1 % of the notes. • Conscious manipulation of the result by the observer is hard to identify.

Risks (continued)	• Causes of fault-related interruptions are hard to identify. • Reasons for workers being absent from their workplace cannot normally be further investigated. • Events to be observed are required to be clearly identifiable. • Persons and participants shall be informed that the method is being applied and shall have understood its purpose so that any impact on the results (by manipulation of events) is prevented. • The normal sequence of operations shall not be disturbed so that the events sampled are representative of the real actual condition. • The quality of the work observed is not considered. • A sufficient number of observations required to ensure the accuracy of data collection and evaluation.

Supplementary figures

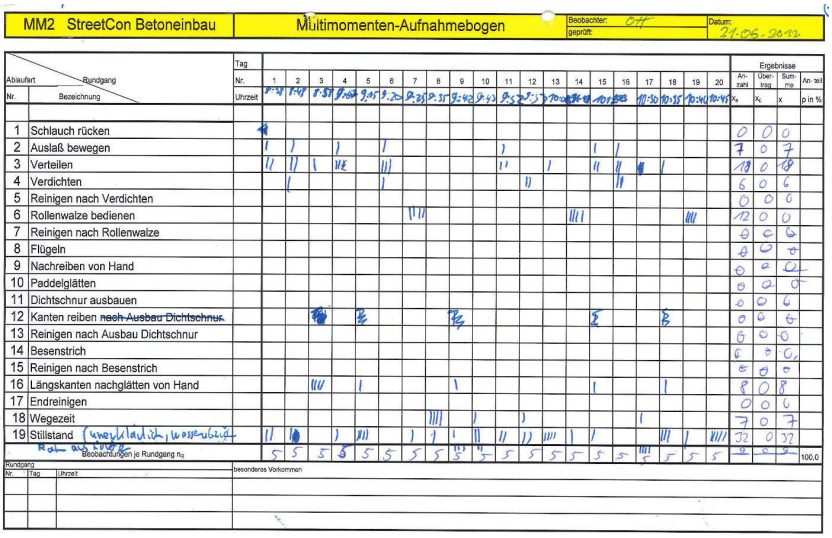
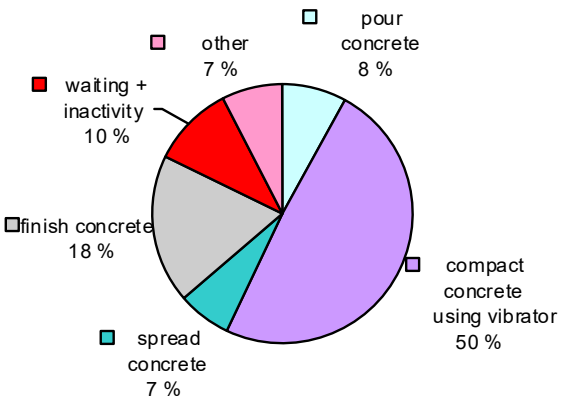


Figure A2. Example of work sampling tally sheet

Category of activity designation	Time in min.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Pour concrete		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1
Compact concrete		4	3	4	3	4	6	6	6	6	6	6	7	6	2	2	2	2	3	3	3
Spread concrete		1	1	1	1	1	1	1	2	2	2	2	1	1	2	1	1			1	
Finish concrete		3	3	2	2	1	3	3	1	1	2	2	2	2	2	2	2	2	5	1	3
Waiting and inactivity		2	3		1	3			1	1				1			2	6	2	3	3
Other				3	3								1		4	5	3			1	1
Workers observed		11	11	11	11	10	11	11	11	11	11	11	11	11	11	11	11	11	11	10	11



➔ **83 % core time**

Figure A3. Example evaluation of working-time distribution obtained from work sampling (example analysis of trough casting in bridge construction)

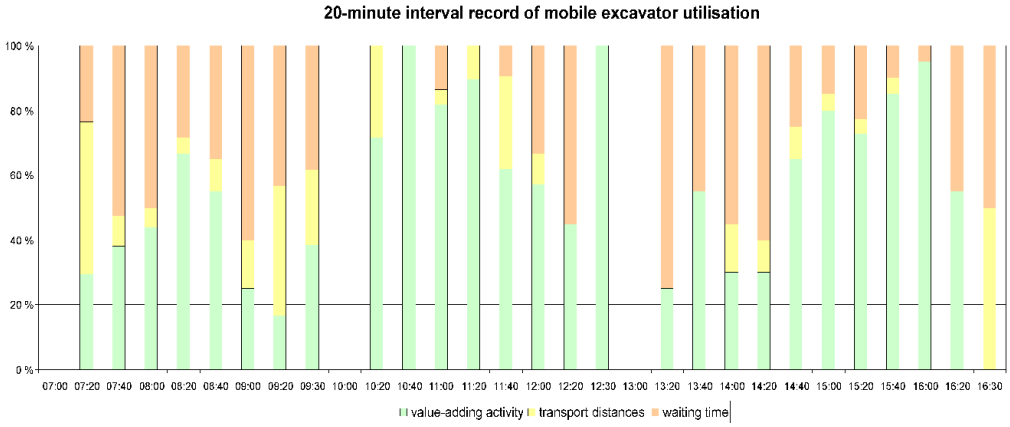


Figure A4. Example evaluation of work sampling to analyse the utilisation of a mobile excavator over the day

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A3 Value stream mapping

Designation	value stream mapping (VSM)
Synonyms	material and information flow mapping, process visualisation
Application area	project and process diagnosis planning and construction processes
Supplementary method	Kanban, FiFo, one-piece-flow
Tools	data collection form, representation using the VSM symbols, time study

Purpose

Value stream mapping and value stream design in construction aim to outline processes in construction planning and execution as well as in administrative areas of the enterprises in a transparent manner. The result is used as a basis for defining an optimised target process with less waste, and appropriate measures for changeover to the target process are initiated.

Brief description

Efficiency on construction sites is determined by the interaction of complex and multi-layer work steps, interfaces, and information flows. Value stream mapping is helpful in representing relations and sequences of processes, material, and information flows in the actual condition in a transparent and clear manner so that the overall process can then be optimised through reduction of waste and harmonisation (or line balancing) of the process times of the individual steps.

First, process, transition, correction and query times, material and information flows, and inventories are recorded and visualised in a clear manner. In the case of abstract processes, it is essential that data collection at the production site/workplace or in a workshop be carried out together with the process performers. As a rule, the persons participating in the process are interviewed to establish details and the communication and information flows.

In particular, the relations between manufacturing processes and information flows, e.g. production/work control, communication with clients or suppliers, are represented (Figure A5 and Figure A6).

Implementation

User groups and application	generally applicable operative and administrative processes in construction, e.g. execution of construction services, planning, purchasing, calculation
Typical duration of implementation	mean duration in the case of manufacturing processes, depending on length and type of process: • diagnosis: one day • evaluation and definition of optimised process: two to three days

Typical duration of implementation (continued)	• implementation of improvement in small steps: two to three weeks • target condition achieved in six to 18 months target: implementation of improvement in short cycles, i.e. within one week to three weeks
Procedure	**Preparation** • selection of the work area and the process to be analysed or the process chains to be analysed • definition of the process boundaries: first and last work steps of the process to be analysed • selection of the work stations or process steps to be analysed • definition of the survey route or the survey sequence of the process steps • selection of the process performers to be interviewed individually or in workshops and their briefing by the supervisors • definition of the survey date and time **Procedure** In value stream mapping, surveys are made on site by one or several persons conducting the analysis (not more than four team members). Those performing the selected process steps can be interviewed individually or during a workshop. The team analyses the processes by means of interviews, observations, and data collection at each process step within the process boundaries. **The procedure consists of the following steps:** 1) recording of the actual process/actual condition of the individual work steps with respect to process, transition, correction and query times, material and information flows, and inventories In the case of production processes, this usually takes place on site, from the process end backwards to its beginning, in order to focus on the prerequisite delivery of the upstream process to the internal process customer. Non-visible processes and activities, e.g. material and information flows, are determined by means of interviews and electronic data collection. It is essential that problems, malfunctions, interruptions, faults, waiting times, and other types of waste as defined by “lean thinking” be recorded matter-of-factly to identify potential fields of activity. 2) complete and clear graphical representation of the actual condition including waste 3) definition of the target process The conception of the target process shall take account of internal specifications such as operating procedure and results from strategy documents. Existing software systems shall also be considered. 4) specification of measures for achieving the target process and compilation of the fields of activity, assigning priorities to the measures according to the following criteria: – Eliminate true waste. – Reduce non-value-adding but necessary activities. – Optimise value-adding activities. 5) presentation/discussion of the results with the management and employees 6) agreeing on further procedure and systematic implementation of the catalogue of measures
Potentials and risks	
Potentials	• ease of recording and representing • transparent representation of process steps, material and information flows, and inventories • enhanced understanding of the actual condition • support of communication • increase in efficiency, particularly when repetitive steps or elements are identified in the analysis • focus on the value adding process
Risks	incorrect conclusions from the instantaneous character of the survey if surveys are not conducted at regular intervals

Supplementary figures

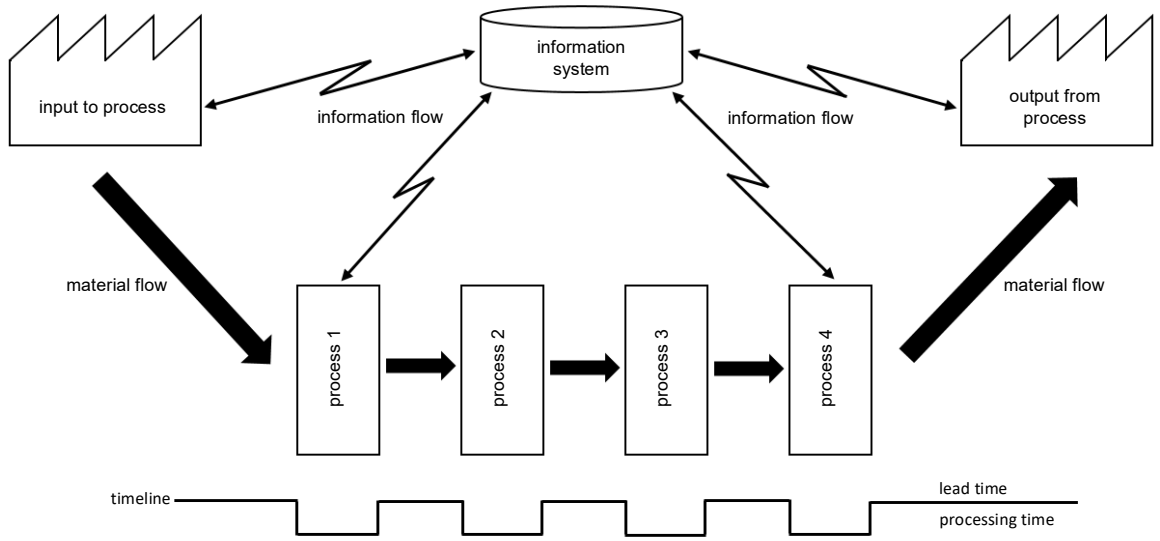

Figure A5. Schematic representation of value stream mapping (VSM) of a production system

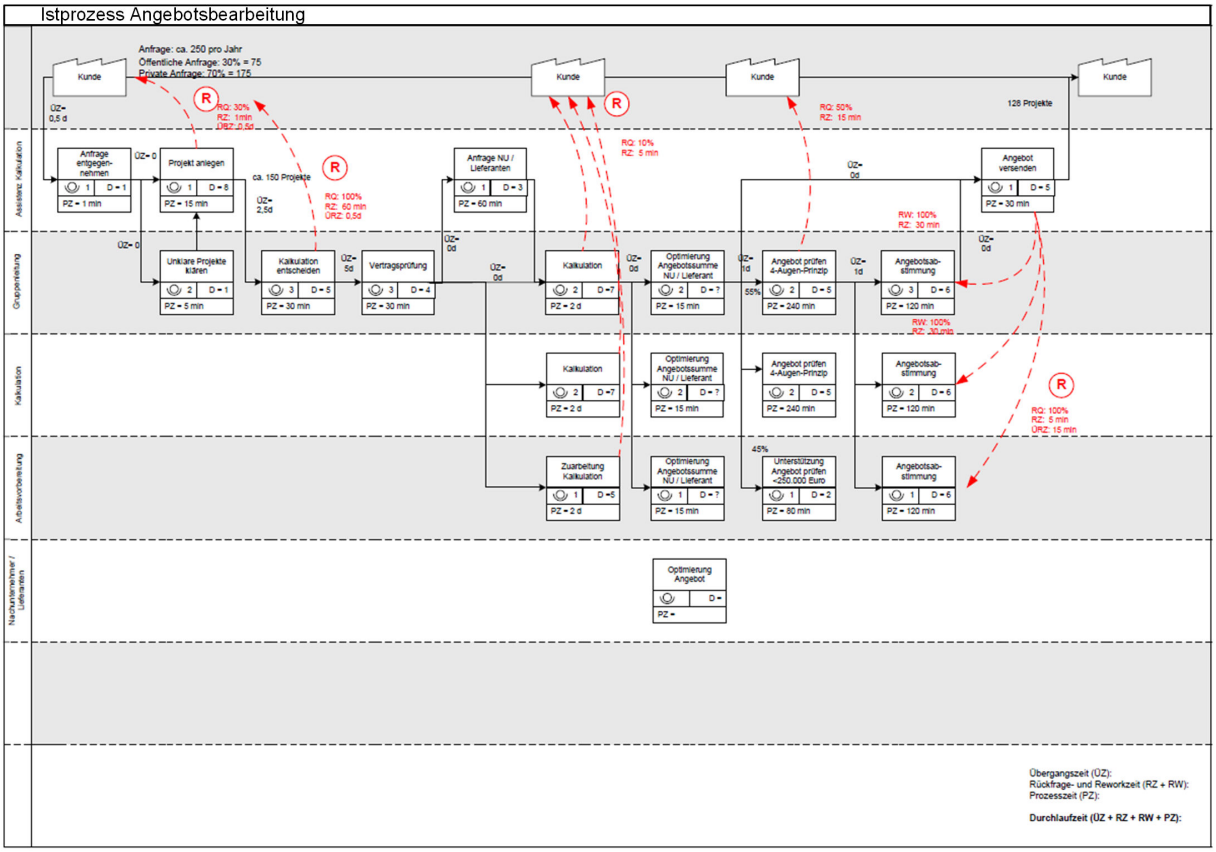

Figure A6. Value stream mapping of tendering in a construction project as one detail process within the overall production system illustrated above (example)

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A4 Spaghetti diagram

Designation	spaghetti diagram
Synonyms	production process analysis
Application area	project and process diagnosis
Supplementary method	waste analysis, 5S; value stream mapping (VSM); work sampling
Tools	layout plan, measurement template

Purpose	
Representation of distances travelled within processes for continuous optimisation of workflows through reduction of waste	
Brief description	
A large number of operations and material flows determine the daily routine on construction sites. The spaghetti diagram is used for the graphical representation and subsequent analysis of the transportation of materials or products and the movement of persons (see Figure A7). It is a representation/analysis of the current situation. If the diagram obtained is tangled and confusing, this indicates waste and hence a potential for improvement. Long paths (lines) and clusters of lines point out possible areas with unnecessary paths.	
Implementation	
User groups	job performers and operative management, e.g., site managers, project controllers, or consultants within a core area on the construction site or in a production area
Typical duration of implementation	• diagnosis: few hours to one day, depending on the size of the area, plus evaluation and implementation of improvement • application at regular intervals
Procedure	1) **Prepare plan** (layout) Draw up a (true-to-scale) plan (e.g. floor layout) for recording and evaluating the paths actually taken by the worker by measuring the lines in the plan. 2) **Specify duration** (period of observation) The decisive question is how long it takes until reliable statements can be made about waste within the process (representative period). The length of the process to be observed is the basis for the period (period of observation) to be analysed. Example: If it takes four minutes to install a drywall panel, it will suffice to observe this process over a period of one hour. If, however, the installation of the stud frame is analysed and this process takes two hours for one work package, then the installation of several walls shall be observed over one day in order to arrive at reliable statements about waste. 3) **Draw in lines for paths taken** As the layout plan is used as the basis for the paths taken during the process, lines corresponding to the path actually taken are drawn in it. This will often allow deriving an optimisation of the workplace organisation (material stores, tools, etc.). 4) **Quantitative evaluation of the spaghetti diagram** For quantitative evaluation, the lengths of the individual lines (paths) in the plan are measured and the total distance travelled is calculated. A simple table relating locations and paths to each other is used for evaluation. Additionally, data such as walking and grasping routes, interruptions, transportation paths and times can be recorded and evaluated. 5) **Steps for optimising the situation** Following evaluation of the current situation, the potentials for optimisation are analysed and implemented. For instance, the following questions have to be answered: – How can transportation and movement routes be optimised, by shortening or avoiding them? – Can storage areas be relocated to spatially limit processes? – Can activities be concentrated spatially to shorten or avoid transportation and movement?

Potentials and risks	
Potentials	• identification and visualisation of the waste types transportation and movement • optimisation of the production layout to reduce waste and hence increase productivity
Risks	• The evaluation of a spaghetti diagram begins as early as the observation phase and consequently influences the results.

Supplementary figures

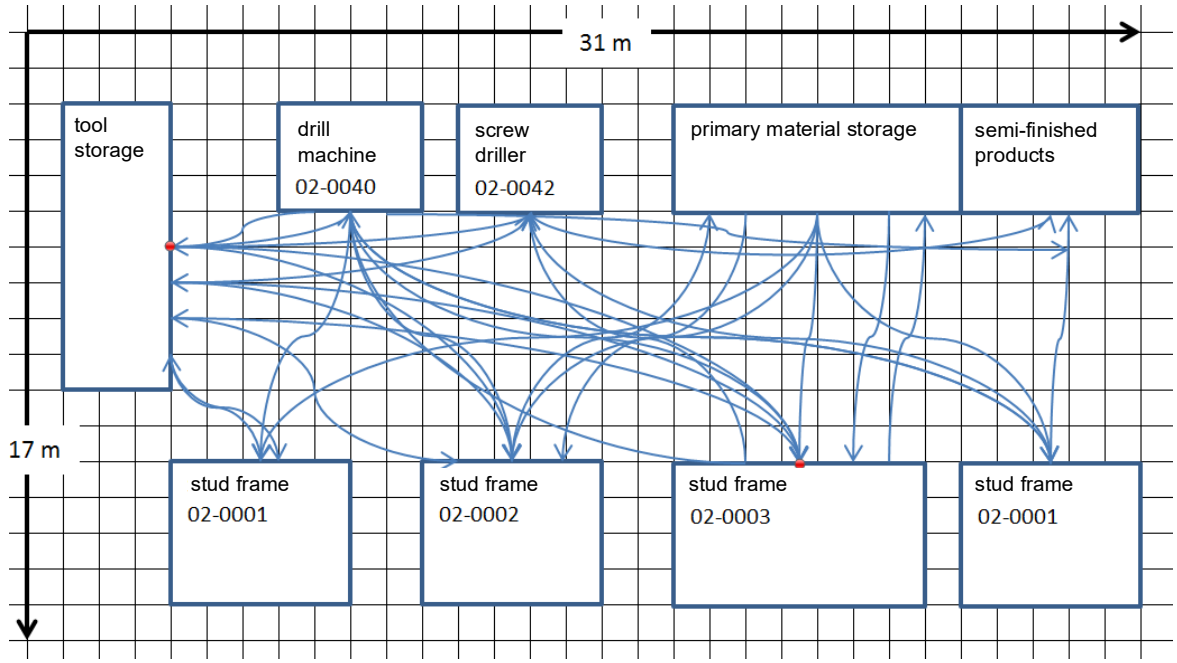

Figure A7. Spaghetti diagram (example)

Remark: Use different line types when observing several persons.

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A5 Material and information flow analysis

Designation	material and information flow analysis
Synonyms	MIFA, material and information flow chart (MIFC)
Application area	process analysis – visualisation of information and material flows analysis of smaller production areas
Supplementary method	value stream mapping (VSM); spaghetti diagram; work sampling
Tools	qualitative data collection and visualisation

Purpose

The purpose of a material and information flow chart is to

- visualise, analyse, and understand the information and material flows existing within an area of observation (e.g. construction site, section of a construction site or planning department),
- check information and material flows for completeness, logic, proper granularity, and optimisation potentials in order to reduce waste (waiting times, missing decisions, duplicate communication, etc.),
- establish a basis for subsequent VSM.

Brief description	
On construction sites, the relations between the different departments and trades are often complex and hence cannot be immediately identified. A material and information flow chart (MIFC) is used to visualise the information and material flows in planning, construction execution, and site logistics. Connecting elements are used to represent the paths and mass flows or the frequency, revealing existing bundles and bottlenecks, redundant communication paths, and unstructured decision-making channels (see Figure A8). Typically, material and information flow charts are plotted to optimise site logistics, planning and order processes, and to improve communication flows in site project management and in the coordination of construction partners. Within the construction process analysis, a good option is to combine the MIFC (clearly arranged qualitative results of the processes) with work sampling (quantified analysis of the contributions to value addition). Methodical similarities exist between MIFA and VSM, with MIFA providing a simplified value stream map as the lead times and inventories are not normally quantified here. Where repetitive production processes (e.g. in road construction or precast production) are to be analysed, value stream mapping is better suited.	
Implementation	
User groups	• **during planning**: project manager, CIP staff unit, project assistant design/ purchasing, consultants • **on the construction site**: site manager, project controller or project manager, e.g. in planning departments, consultants
Typical duration of implementation	five to 15 days (analysis with evaluation and discussion of implementation) plus the implementation of defined improvement measures
Procedure	1) outlining the framework for a definition of the project, sub-project, area, or process 2) listing the parties and key persons involved in the project, including contact details and hierarchical level 3) conducting a brief interview with each key person on a) the regular meeting dates, b) the communication flow (contents and structure) c) the purchasing, order processing, and decision-making paths 4) summarise the results in tabular form and representing them in, e.g., a mindmap structure 5) attending the regular meetings over one week and record the essential elements of these regular meetings 6) representation of the regular information flows and the material flows (using different line types) in the MIFC Additionally, the frequency can be indicated by varying the thickness of the connection arrows, e.g., *daily* (bold), *weekly* (medium), *monthly* (thin). 7) consideration and analysis whether control of the existing information and material flows can be improved in terms of procedure/frequency/logic (location, room layout, participants, IT support, and automation of communication flows, etc.) 8) consideration whether and how unnecessary transportation and information flows can be eliminated, based on the seven waste types
Potentials and risks	
Potentials	• visualisation and structuring of information and material flows • elimination of waste due to unstructured information and material flows (Waiting times and decision-making times can be reduced following visualisation; duplicate communication can be avoided.) • improvement of material flows by acceleration of processes and, e.g., shorter transportation distances
Risks	• The analysis can be time-consuming. • Knowledge of and access to the processes and information flows to be analysed are prerequisites.

Supplementary figures

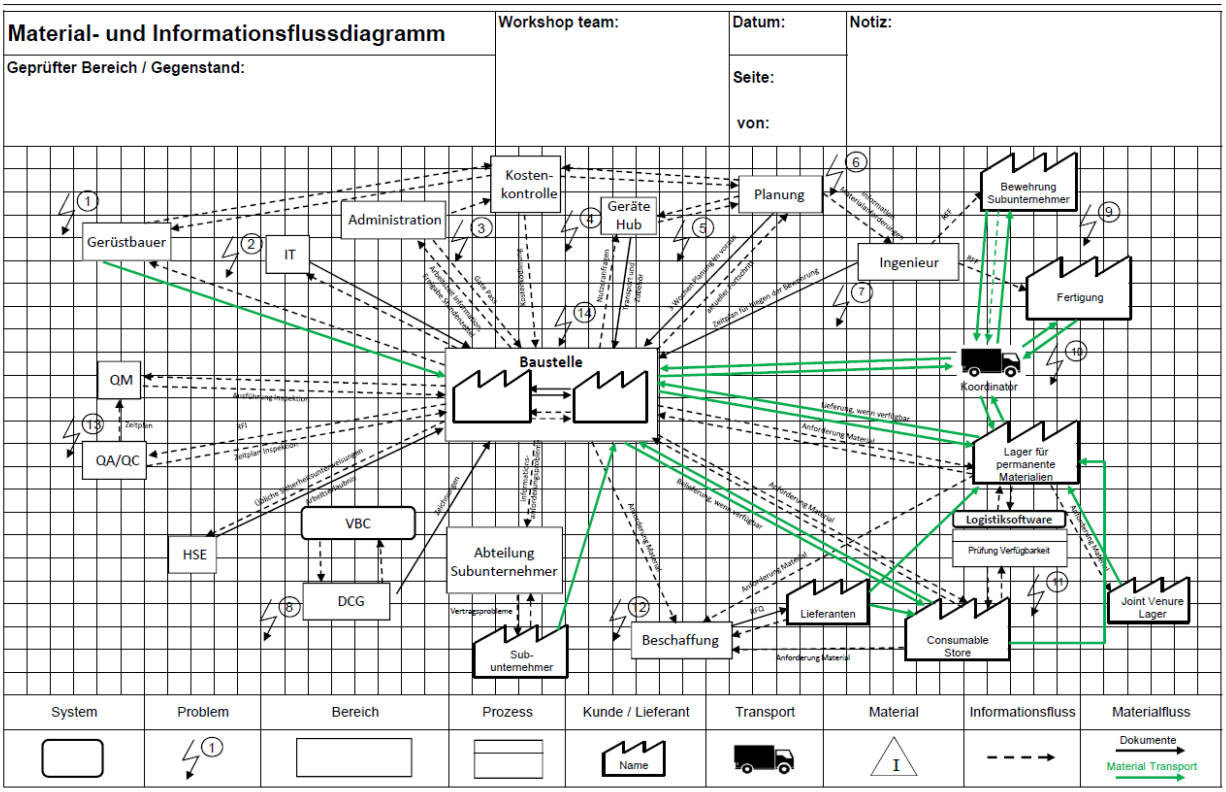

Figure A8. Example material and information flow chart (source: Dreso MIFA Case Study 2017)

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A6 Waste walk

Designation	waste walk
Synonyms	actual waste (MUDA) analysis
Application area	process and project analysis
Supplementary method	MIFA, value stream mapping, work sampling, spaghetti diagram
Tools	KPIs, observation form, time study, where required

Purpose

The purpose is the search for any waste to increase the added value. This is achieved by systematic job-site inspection and logging of observations made in an area of observation.

Brief description

“Waste walk” is a simple method for analysing construction sites to identify waste and improve areas with deficiencies (see Figure A9). During a structured inspection of, e.g., a construction site section or a production unit, the waste observed is recorded systematically as per Section 4.2, Table 2.

Implementation

User groups	planner, project manager, project controller, site manager, foreman, consultant
Typical duration of implementation	one day for the analysis plus evaluation, discussion of results, and implementation of improvements

Procedure	**Preparation** The first step is to establish an overview of the companies involved, the contract and compensation model, an existing logistics concept, etc. These elements have an essential influence on the waste walk results and the improvement potentials to be derived from them. **Analysis** • selection of the area of observation e.g. construction site, section of a construction site, planning office • Implementation of a structured inspection of the area of observation by one person or group to reveal waste according to the eight defined types of waste (Section 4.2, Table 2) • To achieve a representative analysis, the inspection should be repeated at different working time instants. • All elements of waste observed are first listed unsorted in a log, supplemented by visual elements (photos, charts). **Improvement** • Subsequently, the waste elements observed during the inspection are arranged by order of the estimated magnitude of potentials, and measures for improvement are defined together with the persons (e.g. site manager, foremen) performing the specific process. **Follow-up/verification of results** • Sustainability of the achieved improvement is verified by repeating the waste walk after a defined period of time.
Potentials and risks	
Potentials	identification and visualisation of existing waste
Risks	The person conducting the analysis requires extensive practice in identifying the waste types, experience in conveying that the observation aims at the process rather than the employee and to initiate measures for improvement in the group of persons performing the process. Lack of empathy and failure to involve the employees can be counterproductive.
Supplementary figures	

Waste Walk

Location of construction site

Inspection start time:

Inspection end time:

Name of inspector:

	Waste What was observed? (describe example precisely, in note form)	Location	Waste type: Unnecessary transportation	Excess inventory	Waiting	Overproduction	Improper technology/ improper processes	Correction	Unnecessary movement/poor ergonomics	Comments (additional, optional)	Potential of improvement (estimated)
1											
2											
3											
4											
5											
6											
7											
8											
9											
#											

Figure A9. Example waste walk template