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Reference model based on value stream simulation for the evaluation of production systems with the complex material flows in the bidding phase

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When submitting an offer, suppliers of customized production systems (PS) with complex material flows guarantee a minimum throughput (Friedland & Kühling, 2000). There are high risks that the realised material flow does not meet this promise. Oversizing, however, leads to decreased competitiveness. Therefore, a quantitative evaluation of the planning is necessary. Dynamic events, such as setups of machines or varying transport times, lead to interdependencies, with negative effects on the actual throughput. This motivates the idea of using dynamic simulation in the bidding phase.
The value stream method (VSM) (Rother & Shook, 1999) has been efficiently applied for the evaluation of production systems. Thus, we consider its exploitation in the planning process of the bidding phase. The VSM enables a transparent representation of all production processes and associated material and informational flows (Erlach, 2010). However, this static method does not allow for considering stochastic influences and concurrent processes (Luger & Winkler, 2017; Abele, Wolff & Manz, 2012). For the evaluation of such dynamic aspects, discrete event simulation (DES) has proven to be a suitable tool (Friedland & Kühling, 2000). Therefore, we propose a method to combine VSM with DES described as "Dynamic Simulation of Value Streams" (DSVS) by Türck, Weimer, Schubert & Drees, (2014) for the bidding phase.

The primary disadvantage of DES is the time-consuming and costly modelling. Therefore, a detailed planning and simulation often only takes place once the order already has been placed (Friedland & Kühling, 2000). Thus, planning errors are recognized late, leading to unplanned adjustments and considerable risks for time and budget. The modelling effort can be reduced by reference models (RM) – specific for different tasks and application fields – that support the model development (Klinger & Wenzel, 2000). Consequently, we propose a reference model based on DSVS for the bidding phase of production systems. One important challenge is to define the suitable granularity of this model to evaluate interdependencies in production and material flow processes.

For this RM, the subsystems of the VSM (e.g., production processes, material flow, infor-

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mation flow) have to be adapted or supplemented by further elements. This, e.g., concerns process-specific parameters such as the cycle time, which describe the throughput capability of a production step (Erlach, 2010). This capability varies over time, which fact is disregarded in the usual VSM.

Furthermore, a more detailed description of the transport processes is necessary (Gutenschwager, Rabe, Spieckermann & Wenzel, 2017). This includes, amongst other considerations, the type of transport including dynamic factors such as transport time. In current approaches to the DSVS, transport processes were insufficiently respected. The control logics of the production and the associated material flow are vital considerations, too, and form necessary extensions (Türck, Weimer, Schubert & Drees, 2014).

Based on the well-known VSM, the paper proposes a suitable modelling concept (cp. Klinger & Wenzel, 2000) for the simulation reference model. It analyses, which system elements are indispensable for a value-stream-based simulation in the bidding phase. Furthermore, it discusses the level of detail of these elements that matches (i) the requirements of limited aggregation and planning effort in this phase and (ii) the requirements raised by the dynamic character of the production systems.

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Keywords: dynamic value stream, value stream simulation, reference model, simulation in the bidding phase

REFERENCE MODEL BASED ON VALUE STREAM SIMULATION FOR THE EVALUATION OF PRODUCTION SYSTEMS IN THE BIDDING PHASE

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Work in progress

ABSTRACT

When submitting an offer, suppliers of customized production systems (PS) with complex material flows guarantee a minimum throughput (Friedland & Kühling, 2000). There are high risks that the realised material flow does not meet this promise. Oversizing, however, leads to decreased competitiveness. Therefore, a quantitative evaluation of the planning is necessary. Dynamic events, such as setups of machines or varying transport times, lead to interdependencies, with negative effects on the actual throughput. This motivates the idea of using dynamic simulation in the bidding phase.

The value stream method (VSM) (Rother & Shook, 1999) has been efficiently applied for the evaluation of production systems. Thus, we consider its exploitation in the planning process of the bidding phase. The VSM enables a transparent representation of all production processes and associated material and informational flows (Erlach, 2010). However, this static method does not allow for considering stochastic influences and concurrent processes (Luger & Winkler, 2017; Abele, Wolff & Manz, 2012). For the evaluation of such dynamic aspects, discrete event simulation (DES) has proven to be a suitable tool (Friedland & Kühling, 2000). Therefore, we propose a method to combine VSM with DES described as "Dynamic Simulation of Value Streams" (DSVS) by Türck, Weimer, Schubert & Drees, (2014) for the bidding phase.

The primary disadvantage of DES is the time-consuming and costly modelling. Therefore, a detailed planning and simulation often only takes place once the order already has been placed (Friedland & Kühling, 2000). Thus, planning errors are recognized late, leading to unplanned adjustments and considerable risks for time and budget. The modelling effort can be reduced by reference models (RM) – specific for different tasks and application fields – that support the model development (Klinger & Wenzel, 2000). Consequently, we propose a reference model

based on DSVS for the bidding phase of production systems. One important challenge is to define the suitable granularity of this model to evaluate interdependencies in production and material flow processes.

For this RM, the subsystems of the VSM (e.g., production processes, material flow, information flow) have to be adapted or supplemented by further elements. This, e.g., concerns process-specific parameters such as the cycle time, which describe the throughput capability of a production step (Erlach, 2010). This capability varies over time, which fact is disregarded in the usual VSM.

Furthermore, a more detailed description of the transport processes is necessary (Gutenschwager, Rabe, Spieckermann & Wenzel, 2017). This includes, amongst other considerations, the type of transport including dynamic factors such as transport time. In current approaches to the DSVS, transport processes were insufficiently respected. The control logics of the production and the associated material flow are vital considerations, too, and form necessary extensions (Türck, Weimer, Schubert & Drees, 2014).

Based on the well-known VSM, the paper proposes a suitable modelling concept (cp. Klinger & Wenzel, 2000) for the simulation reference model. It analyses, which system elements are indispensable for a value-stream-based simulation in the bidding phase. Furthermore, it discusses the level of detail of these elements that matches (i) the requirements of limited aggregation and planning effort in this phase and (ii) the requirements raised by the dynamic character of the production systems.

1. INTRODUCTION

The planning of a customized automated production system (PS) with complex material flow is determined by its complexity. The consideration of every customer request causes adjustments of the planning already during the bidding phase. Furthermore, with submitting a customized offer, suppliers guarantee a minimum throughput (Friedland & Kühling, 2000). If a realized PS with complex material flow does not fulfil the promised throughput, high financial costs can occur. Oversizing restricts competitiveness. Therefore, the suppliers aim to safeguard their planning, concerning the guaranteed throughput, in the bidding phase.

For this purpose, the entire material flow of the PS must be analysed for design errors. The value stream method (VSM) enables a clear representation of the material and information flows as well as their evaluation (Börkircher & Gamber, 2010). However, this method cannot be used to map the effects of randomly occurring events, such as stochastic failures of operating resources (Luger & Winkler, 2017). The evaluation of such dynamic interdependencies within a production system with complex material flow requires, among other things, the use of simulation (Friedland & Kühling, 2000). This allows for considering dynamic systems over time, in executable models (Gutenschwager et al., 2017).

Simulation, however, is time-consuming, costly, and, therefore, not appropriate for the bidding phase. Furthermore, only a small part of offers leads to a successful acquisition. Therefore, a detailed planning with simulation often starts when the order has already been placed (Friedland & Kühling, 2000). Thus, planning errors are recognized too late and lead to planning adjustments with delays and financial risk. This raises the demand for a low modelling effort for simulation, concurrently with a high security of planning in the bidding phase (Friedland & Kühling, 2000). Therefore, a scientific method is proposed for the configuration and simulation of a material flow in a PS, based on the VSM, which is reasonably useable in the bidding phase.

2. VALUE STREAM METHOD

The value stream method (VSM) enables a transparent representation of all product-specific production processes with associated material and informational flows in discrete manufacturing. This includes the complete production, starting from the customer going back to the supplier. Process-specific parameters enable rapid detection of design errors. The described transparency is achieved by six basic elements, which are represented by the pictograms in

Figure 1 (Erlach, 2010). The method can be assigned to the Toyota Production System (TPS) and has established itself as part of *Lean Production* (Rother & Shook, 1999).

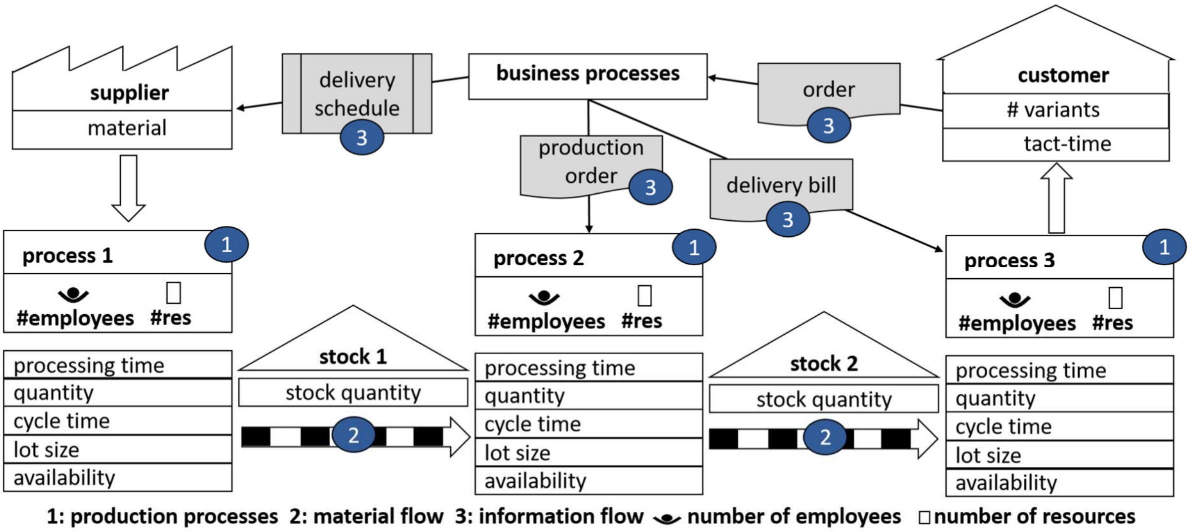

Figure 1: Application of a value stream (based on Erlach, 2010)

The VSM is divided into two application areas, value stream analysis (VSA) and value stream design (VSD): The VSA reveals the current situation and potential for improvement (Pfeffer, 2014). Based on the recorded actual situation, VSD enables a restructuring of production to eliminate non-value-adding activities. For customer-focused implementation, this area contains several structured design principles. The result is a model-like illustration of the target concept, which can be used as a proof for the improvement potential of production (Erlach, 2010).

The analysis of production systems with complex material flows involves a large number of interdependent and mutually influencing system variables (Friedland & Kühling, 2000). This includes stochastic influences like machine breakdowns or concurrent processes (Gutenschwager et al., 2017). These interdependencies cannot be adequately mapped with a static VSM or mathematical-analytical methods. For the evaluation of such dynamic aspects, discrete event simulation (DES) has been recognised to be a suitable approach (Friedland & Kühling, 2000).

3. SIMULATION

In production and logistics, simulation is defined as a “representation of a system with its dynamic processes in an experimentable model to reach findings which are transferable to reality; in particular, the processes are developed over time“ (VDI, 2014). According to this definition, this method distinguishes itself from static analyses, which cannot represent the dynamics of the system using an executable model. These executable models (simulation models) enable analyses of the system behaviour after parameter or structure changes. Insights into the behaviour of systems can be derived from experiments with simulation models. Thus, simulation is not a problem-solving method on itself. Discrete event simulation (DES) is the most frequently used simulation method in production and logistics (Gutenschwager et al., 2017). Asides its advantages, simulation usually has the following downsides (Solding & Gullander, 2009; Abele, Wolff, Manz, 2012):

- An exact understanding of the system is necessary for the creation of simulation models. Modelling is, therefore, time-consuming and resource-intensive.
- For the use of simulation models, large amounts of data are required.

For simulation in the bidding phase, the effort of a system analysis and its data request can be ignored, because the supplier has the necessary system understanding and database. The primary deficit of the simulation is the time-consuming modelling. To reduce this effort, so-called reference models (RM) exist, which support the user in creating the model (Friedland & Kühling, 2000).

3.1. Reference model (RM)

A reference model includes a systematic and generally valid description of a defined area of the real world with the characteristic properties relevant for a given task and defines the associated modelling concept. In the field of simulation, reference models serve as design schemes for the design of task-related simulation models (Klinger & Wenzel, 2000). Therefore, a reference model is at the same semantic level as the model that is mapped with it. It focuses on the semantic and generalizes the syntax. In contrast, a meta model is a model´s model, which describes the syntax of the model system and generalizes the semantic (Schütte, 1998).

Furthermore, a reference model does not consider the system architecture of a simulation system. Thus, the model element box of a simulation system is not a reference model, but a simulator-specific implementation of a reference model (Klinger & Wenzel, 2000).

3.2. Dynamic value stream method

Combining the "value stream" Lean Method with simulation is not a new approach. The first ideas were in the digitalization of the value stream. The value stream input is not via paper and pencil-based methods, but via computer-aided systems such as the *WertStromDesigner*. This enables a simpler representation and analysis of the value stream, supported by a discrete event simulation (Erlach, Halmosi, Löffler, 2003). Another approach is the program *ProVSM* from the field of process analysis. This program focusses on business processes. An illustration of the value stream is possible and the individual processes can be simulated (Wildemann, 2005). However, both systems lack a detailed view of the material flow and its possibility for optimization (Brüggemann & Müller, 2008).

Brüggemann and Müller (2008) take this into account. They present a module for the integration of the value stream design into a commercial software tool. Amongst other things, buffer allocations can be determined. Börkirchen and Gamber (2010) build on the existing knowledge and extend the dynamic consideration of the value stream by flow disturbances, integrating the consideration of flow alternatives. The dynamic VSM can be created with different modelling approaches, such as an element box that includes the typical elements of VSM for a modelling via drag and drop (Wincheringer & Preiß, 2017).

Studies at an automotive supplier also prove the usefulness and advantages of a value stream method extended by simulation. In this way, inventories and the associated throughput times are significantly reduced. However, further research approaches are needed to transfer the static value stream method to simulation (Abele, Wolff, Manz, 2012). There is consensus that a transfer is possible, but that the significance of the dynamic value stream simulation depends on the degree of detail of the value stream description. The VSM does not have the granularity of a material flow simulation and, thus, uses a system approach that is too superficial (Türck, Weimer, Schubert, Drees, 2014).

Implemented tools, such as *SimVSM*, confirm this. They enable value stream modelling via mobile devices and simulation. Alternative value streams are evaluated in the form of cycle times or inventories. However, stochastic customer requirements, process uncertainties and transport variants are not taken into account (Meudt, Kaiser, Metternich, Spieckermann, 2017). The material flow control of real production systems is much more complicated than the VSM can map (Spieckermann, Stauber, Wedel, 2019).

All publications and approaches have in common that the VSM was transferred into simulation systems or supplemented by these. Their intention was to get a dynamic Lean-method (Drees, 2018). For the assurance of the planning quality in the bidding phase with value stream simulation, however, an increased granularity is required (Figure 2).

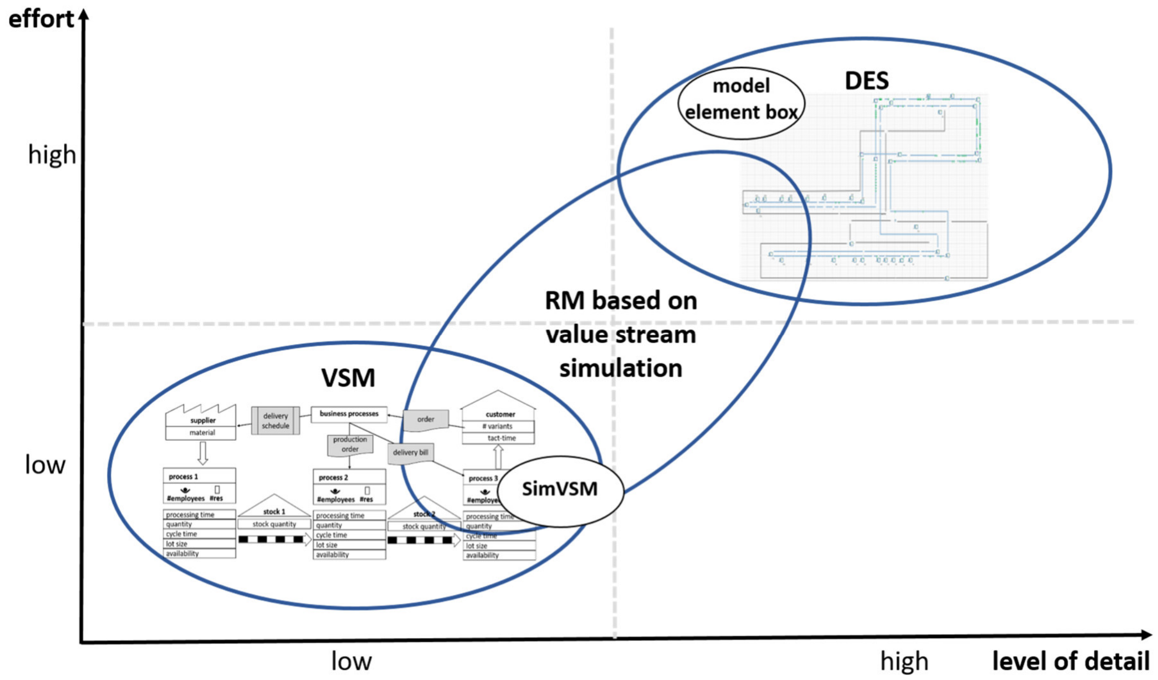

Figure 2: Overview of the methods: level of detail and effort

The PS, with its complex material flow, must be depicted with sufficient precision to be able to be operated by means of a high quality planning to create a quotation that is as accurate as possible. This includes, in addition to the manufacturing processes, the consideration of transport processes and material flow logic.

The advantages of the VSM, the DES, and the RM should be combined with each other. This includes the transparency of VSM, the dynamic of DES and the reduced modelling-effort by a RM. Aspects of a PS like the material flow logic, discontinuous conveying, and production processes have a direct influence on the modelling effort. The question is, which granularity of a reference model based on value stream simulation is necessary for simulation in the bidding phase.

Clients generally request detailed simulation models for their modelling analyses. According to their conception, a detailed image accuracy requires better results (Rank, Hammel, Schmidt, Schneider, 2015). However, studies show that at a certain point the increase in accuracy decreases or even becomes negative (Figure 3). There is no universal definition of when a model is too detailed (Rank, Hammel, Schmidt, Schneider, 2015). The challenge is to find the right level of detail in accordance with the guiding principle "as detailed as necessary" (ASIM, 1997). In this case, we aim the maximum accuracy of results with a minimum level of detail (see the circle in Figure 3).

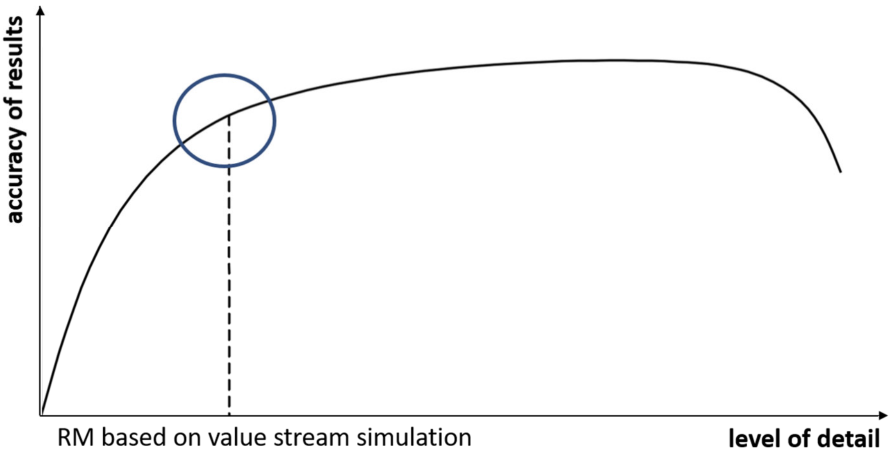

Figure 3: Simulation model level of detail and accuracy (based on Robinson, 2008)

4. STRUCTURE OF THE REFERENCE MODEL

For the combination of the VSM with the material flow simulation, it is necessary to determine the suitable granularity of the database and the process descriptions. Furthermore, the simulation must be based on the reference model to reduce the modelling effort. Basing the modelling on the VSM, its basic elements *production process*, *material-,* and *information flow* have to be analysed.

In order to see the necessary modifications, an example with a classic VSM is given: after the assembly process on machine Q, the product can be checked on process A or B. The regular material flow is carried out via a direct connection from Q to A by a continuous conveyor (e.g., a conveyor belt). If process A breaks down or is blocked, the product will be transported to B by a discontinuous conveyor, e.g., an automated guided vehicle (AGV) (Figure 4).

4.1. Production process

The production process in VSM is represented by a data box, including production-specific key performance indicators (KPIs). Nevertheless, certain existing parameters are to be supplemented by the dynamic considerations for a simulation. Not every KPI is necessary to describe a production system with material flow, depending on the modelling task. E.g., an annealing furnace needs five hours for its process; the set-up only takes five minutes. Thus, we only have to focus on the annealing process. In contrast, an assembly process with small production lots needs 20 minutes for assembling; a set-up takes up to 1.5 hours. Therefore, it is necessary to look at both KPIs. To map any possible eventualities, all KPIs are described in detail.

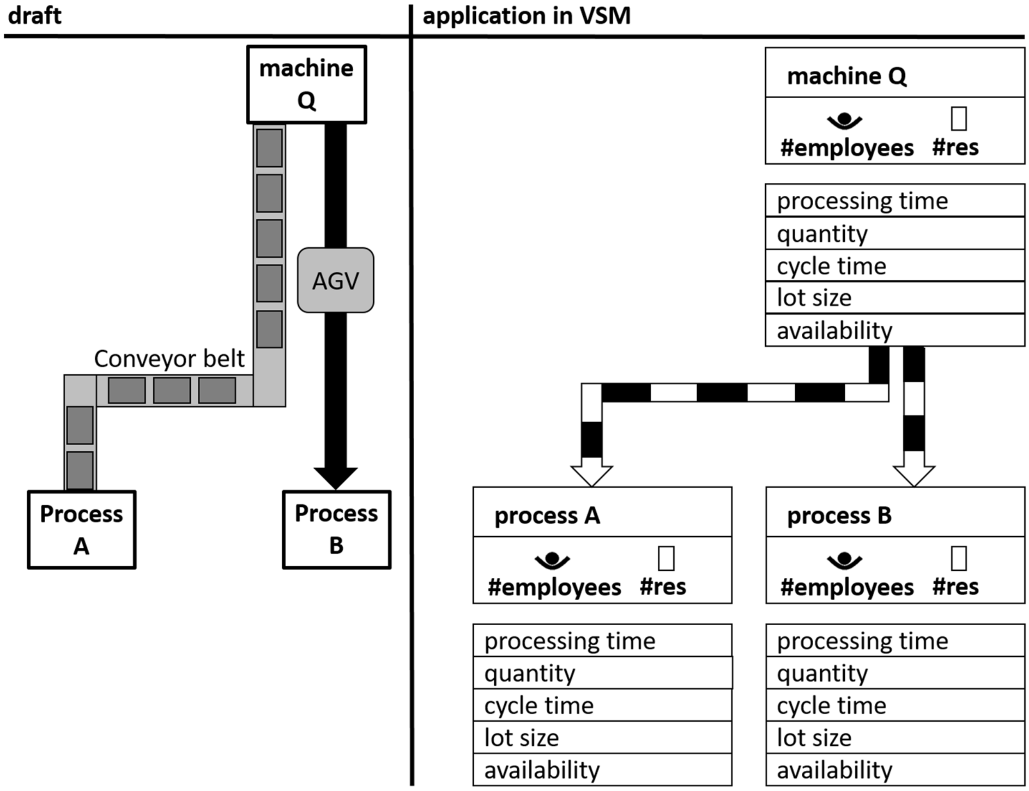

Figure 4: Example of a material flow

The *cycle time* describes the throughput capability of a production step. This parameter depends on the *processing time*, the *process quantity,* and the *number of resources* (Erlach, 2010). The cycle time must be stored product- and process-specifically. Taking into account the specific availability of a resource enables the determination of an existing bottleneck (Brüggemann & Müller, 2008).

The *processing time* characterises how long units stay in a production process. It represents continuous processes (e.g., continuous furnace) as well as batch processes (e.g., varnishing shop) (Erlach, 2010). This parameter must be mapped identically to the cycle time, including the product- and process-specific value.

The *process quantity* represents the number of units integrated into one batch (Erlach, 2010). For the simulation, the different products must be considered, in order to represent main and side material flows for assembly processes.

Specifying a time interval to represent the *set-up time* is not sufficient to capture the dynamics. Order-related event tasks, lot sizes that require a set-up action, as well as stochastic periods of set up time must be taken into account (Gutenschwager et al., 2017).

Similarly, a percentage of *availability* is not adequate for a simulation. For this purpose, the parameter must be extended by the points in time of failure in the form of distributions like the exponential distribution (Gutenschwager et. al., 2017), number of actions until a failure occurs, or events that cause a disruption. In addition, the period of repair in conjunction with a distribution like the Erlang distribution, must be adapted (Gutenschwager et al., 2017).

In addition, the *production yield*, depending on products and raw materials, of an operating resource must be adapted. Stochastic events that cause a rejection as well as the quantity dynamics of bad parts must be taken into account (Gutenschwager et al., 2017).

Figure 5 shows the static VSM representation of a production process, amended by the necessary parameters for a simulation.

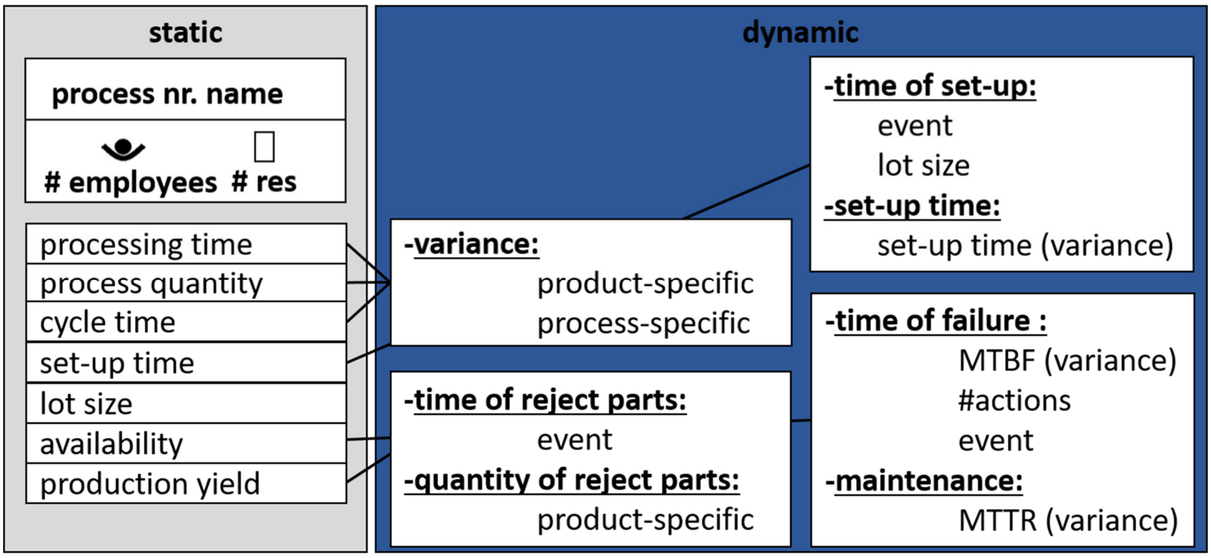

Figure 5: Standard VSM amended by the necessary parameters for a simulation

4.2. Material flow

The material flow of the VSM is only represented by arrow symbols and material stocks in the form of triangles, whereas production processes are described at a more-detailed level via data boxes. For more detail, Knössl provides a static extension, adding aspects of logistics functions to the VSM: He defines, among other things, quantity-based transformation of goods (Knössl, 2013).

Quantitative transformations can be subdivided into sorting and collecting. Sorters like switches, lifts, or sliding units sort goods and enable a material flow in different directions. In this case, the processing time depends on the direction of travel, e.g., if the sliding units do a travel motion to conveyor 1, 2, or 3. Concerning the switch, the processing time depends on the toggle time. Collectors are technically insignificantly different from the sorter. They summarize units of different material flows and enable one material flow direction (Figure 6) (Arnold & Furmans, 2009).

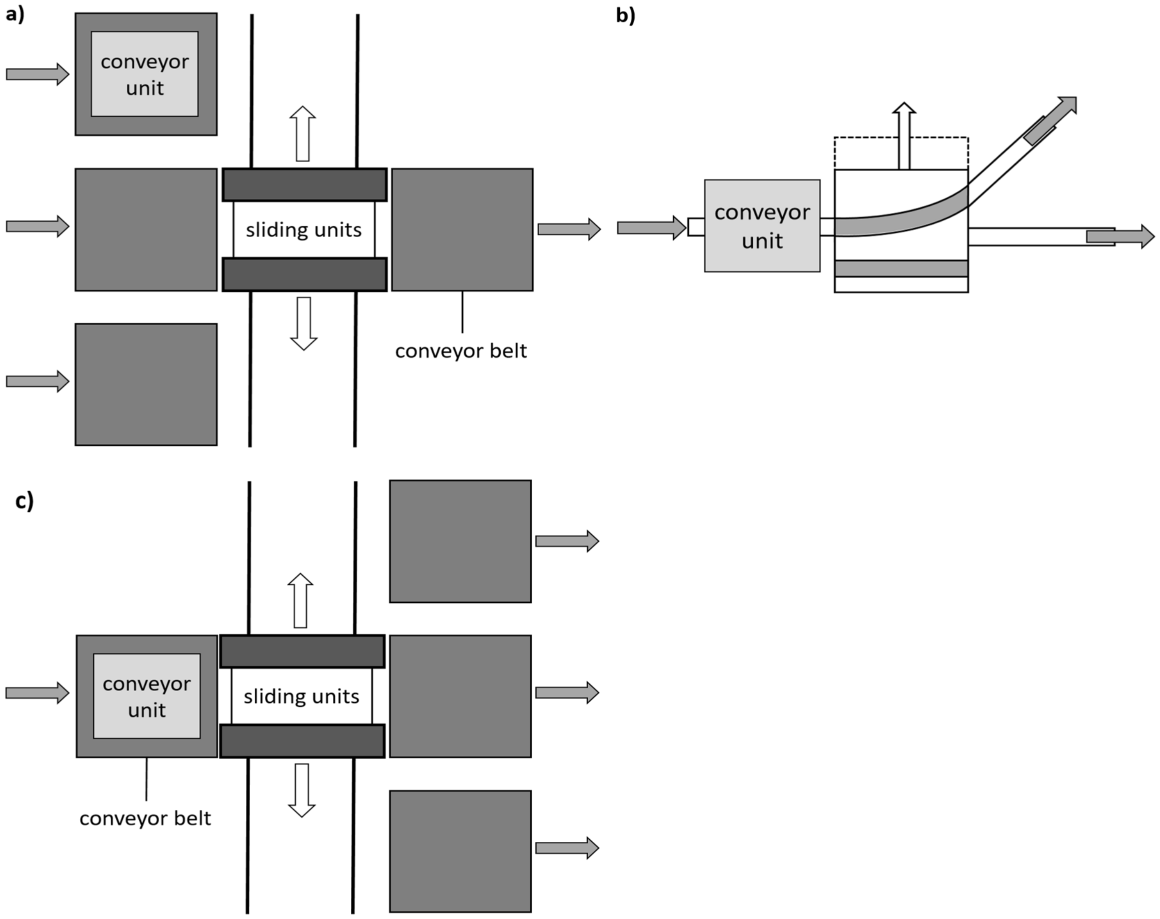

Figure 6: a) sorter: sliding units b) sorter: switch c) collector: sliding unit (based on Arnold & Furmans, 2009)

All these functions of quantity-based transformation of goods can be represented with KPIs, which are previously defined at the data box for production processes amended by the necessary parameters for a simulation (Figure 7).

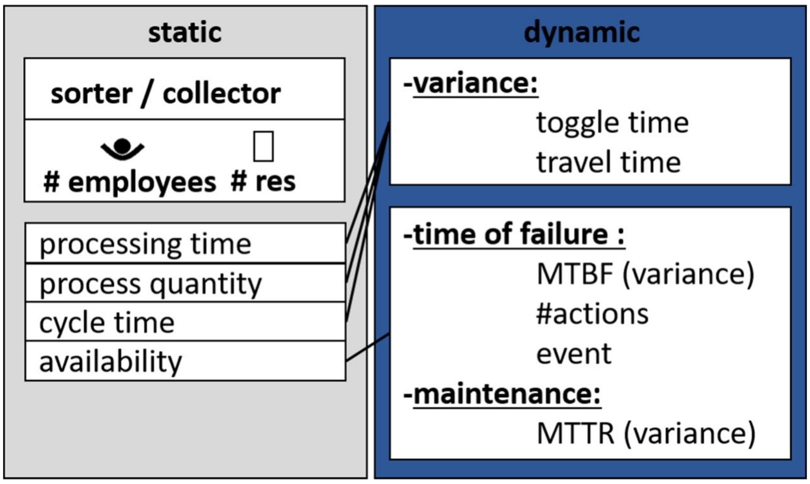

Figure 7: Sorter and collector represented with the data box for production processes

In contrast, logistics functions for the geographical and temporal transformation of goods, like conveying or transporting, are special and cannot be represented with KPIs for a production process. An extended data box with process variables for transport is needed (Knössl, 2013). For a detailed description, it must be determined which KPIs are useful to define a transport process and are necessary for simulation in the bidding phase. Thus, it is useful to consider which aspects are taken into consideration in the planning of conveyor systems. Depending on the modelling situation, not every KPI has to be respected. For example, the acceleration of a conveyor belt A with 30 m length has not the same influence as the acceleration of a conveyor belt B with 2 m length. The influence of the acceleration of conveyor belt A is too small, so it can be ignored. To map any eventualities, all KPIs are described in detail.

With reference to the discrete manufacturing material flow of goods, conveyors generate a continuous or discontinuous flow of conveyed material. Therefore, two different types of conveyors – continuous and discontinuous – exist. Continuous conveyors (e.g., a conveyor belt) are always equipped with fixed guideways; their flexibility is limited. Loading and unloading can take place during the transport process. Depending on the type of these conveyor belts, an accumulation of the material is possible (ten Hompel, Schmidt, Dregge, 2018). In comparison, discontinuous conveyors (e.g., an AGV) can move freely and, therefore, have a higher degree of flexibility in general. In most cases, the loading and unloading process takes place while the conveyor stops (ten Hompel et al., 2018).

The loading and unloading process can be represented with the previously defined data box for production processes amended by the necessary parameters for a simulation. This includes also special cases, like an AGV executing the transfers during the journey. In this case, the processing time for loading and unloading is zero. Thus, the focus is on the conveying as "the internal movement or change of location of the object of work" (ten Hompel et al., 2018). According to this description, it is possible to determine a data box that characterizes the conveying processes in general, regardless whether it is a continuous or discontinuous system.

A major KPI is the *cycle time*, which represents the *transport time* of a conveying unit. This depends on the length of the *conveying distance*, the conveyor's *speed, acceleration*, and *deceleration*. Concerning the conveying distance of discontinuous conveyors, it has to be defined where the *source* and *sink* are (VDI, 2018; Knössl, 2013). Furthermore, the *path* determined by crossings and block points has to be respected.

Besides, the *capacity* of a conveyor system has to be considered. The capacity represents the physically possible loading volume (Knössl, 2013; Kadachi, 2003).

In addition to mapping the transport volume of discontinuous conveyors, the congestion situation must also be taken into account for continuous conveyors (Kadachi, 2003). For example: If M2 is out of order, the material accumulates on the roller conveyor until M1 and its production process stops (Figure 8).

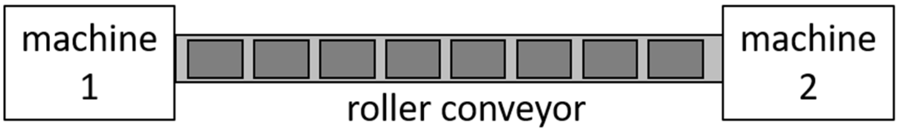

Figure 8: Application of a roller conveyor (Kadachi, 2003)

Thus, the congestion behaviour of discrete manufacturing material must be considered. To represent the material flow with the necessary accuracy we need the *distance* between the parts on a conveyor. With this information, it is possible to represent roller conveyors that maintain a minimum distance between the conveyed goods (distance > 0), roller conveyors that clock discretely (distance = x) and conveyors whose entire physical length can be equipped with goods (distance = 0) (ten Hompel et al., 2018; Kadachi, 2003).

Conveyors are not only used for material transport, but they also divide production processes (ten Hompel et al., 2018), which is represented by their minimum and maximum *buffer* size.

Furthermore, the *availability* is useful to define the time slice of a conveyor system when it is available fault-free. For the purpose of simulation, stochastic influences have to be defined, identical to the production processes (VDI, 2018).

Figure 9 summarizes the results. The material flow representation of the VSM is extended by a data box with the parameters for a sufficiently accurate representation of reality. These represent conveying processes in general.

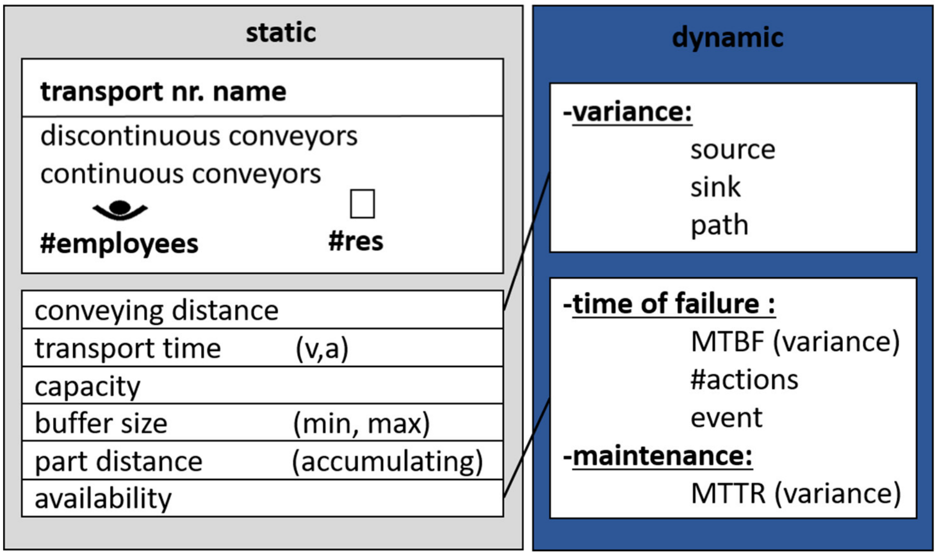

Figure 9: Data box to represent a transport with VSM

4.3. Information flow

The adjustments of the VSM process data box and the consideration of the VSM conveying processes with KPIs provide the necessary information to define production and logistic processes for a simulation model. Their combination requires a logistic connection. Therefore, the VSM includes the aspects of order handling, subdivided into business processes, information flow, and logistic connections. Business processes visualise the production planning and control system (PPC), and the information flow presents the data stream between production processes, material flow processes, or business processes. The logistic function combines the business processes, the information flow, and the material flow (Erlach, 2010).

Nevertheless, the VSM and the existing approaches of the value stream simulation consider the material flow logics too superficially for a simulation (Türck et al., 2014). Concurrent processes, stochastic influences, and assembly processes with various products are not taken into consideration. Thus, we add a further element to the basic elements of the VSM, the *logic*. It includes, among others, the material flow logic, in order to combine production processes with a conveyor or to link production processes. This could be realised with stochastic or with if-else-rules (Figure 10).

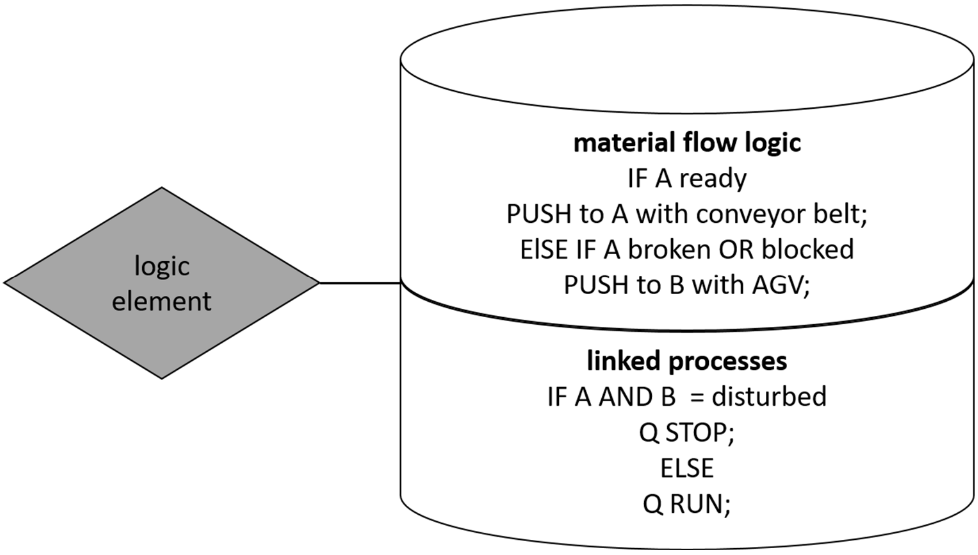

Figure 10: Example for the illustration of the material flow logic

Figure 11 shows the previous example of Chapter 4 mapped with the VSM extended by the dynamic aspects. Furthermore, it shows the logic of the linked production processes: As soon as process A and B are disturbed, process Q must stop. It keeps on working when minimum one affected process is repaired.

4.4. Product

The VSM only analyses the value stream of one discrete manufacturing product or product type (Solding & Gullander, 2010). For a realistic value stream, different products with different cycle times and behaviours will be respected (Solding & Gullander, 2010). This enables a representation of value streams and assembly processes with different units depending on various production orders. Therefore, a further element to the VSM, the *product,* is added (Figure 12).

The approach is to map a product with specific attributes. This could include the lot size, the whole process sequence as well as the information on source and sink. Which attributes are necessary depends on the level of detail. The product-specific attribute is queried at the respective process, which leads to different events.

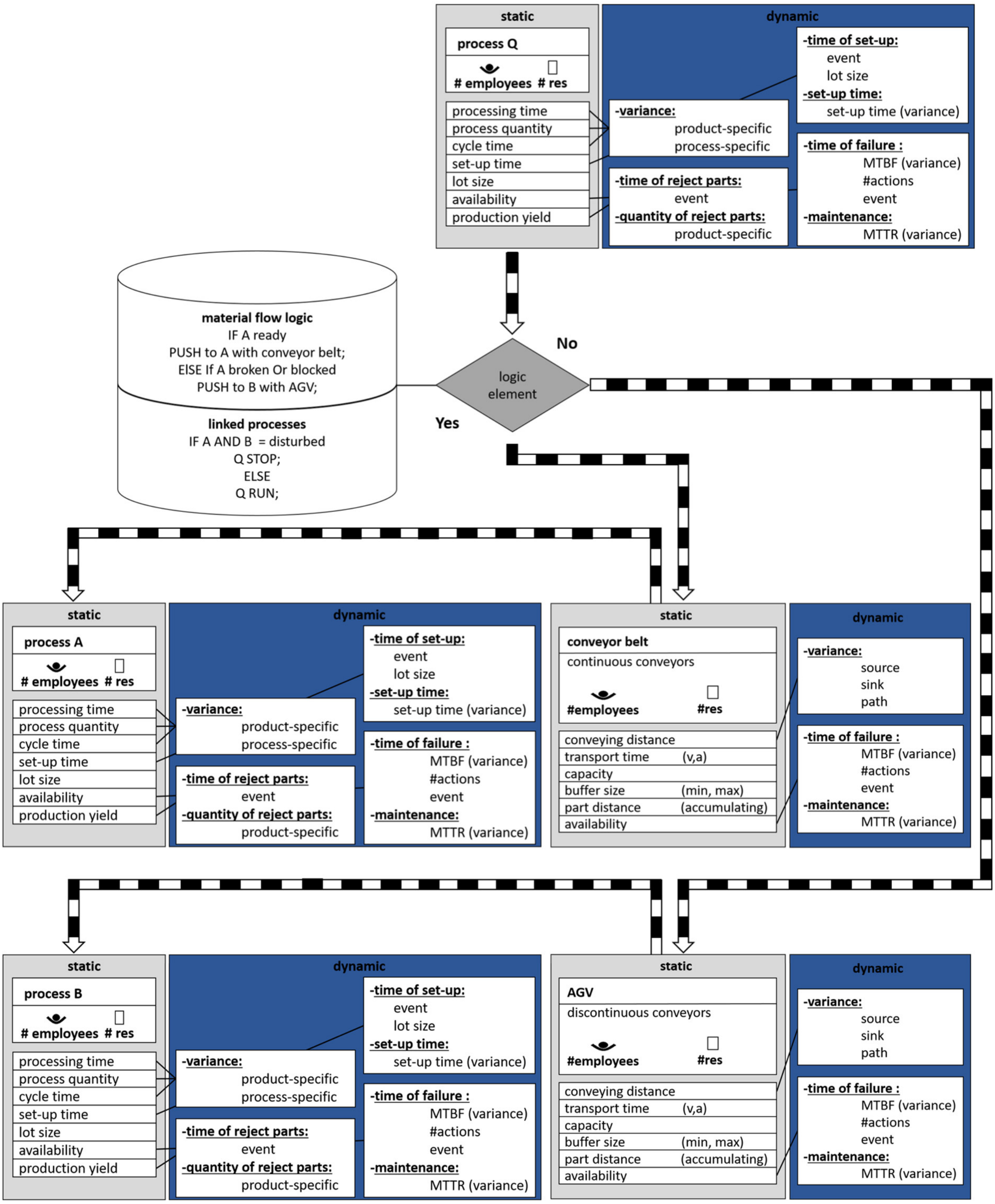

Figure 11: Example of the value stream of Chapter 4 extended by the dynamic aspects

4.5. Level of detail for a reference model

Analysing a PS with complex material flow, several dynamic aspects must be taken into account. For the RM based on value stream simulation, the VSM was adapted by necessary KPIs. In order to allow for simple modelling of the production system, the challenge is to define the level of detail, including the logic aspects. Therefore, several existing possibilities and approaches must be considered. The level of detail depends, among other things, on the required result parameters (Gutenschwager et al., 2017). For this consideration, methods exist that support or classify the choice of the suitable degree of abstraction. The final determination of the degree of abstraction or level of detail for a reference model, based on value stream simulation in the bidding phase, is going to be discussed in further research.

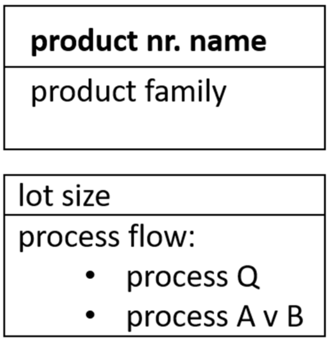

Figure 12: Application of a product type

5. REFERENCE MODEL BASED ON VSM

The goal of combining the static VSM with the simulation is to integrate the advantages of both methods (Solding & Gullander, 2010). Because of this, the big benefit of VSM, the simple visualisation of a production system, should be preserved. Thus, the modelling with the reference model should be related to the standard VSM mapping.

Furthermore, data such as the cycle and transport time should be taken into account for each process. A timing chart of the cycle and transport times enables the detection of bottlenecks. Figure 13 shows how a simulation model, modelled with the reference model based on value stream simulation, would look like.

In addition to the level of detail for the reference model, a cost-benefit evaluation is necessary to determine the effort of modelling with the reference model based on value stream simulation. This evaluation and the aspects of mapping stocks and buffers, the integration of the timing chart, and the definition of necessary results (like throughput and lead-time) are going to be discussed in further research.

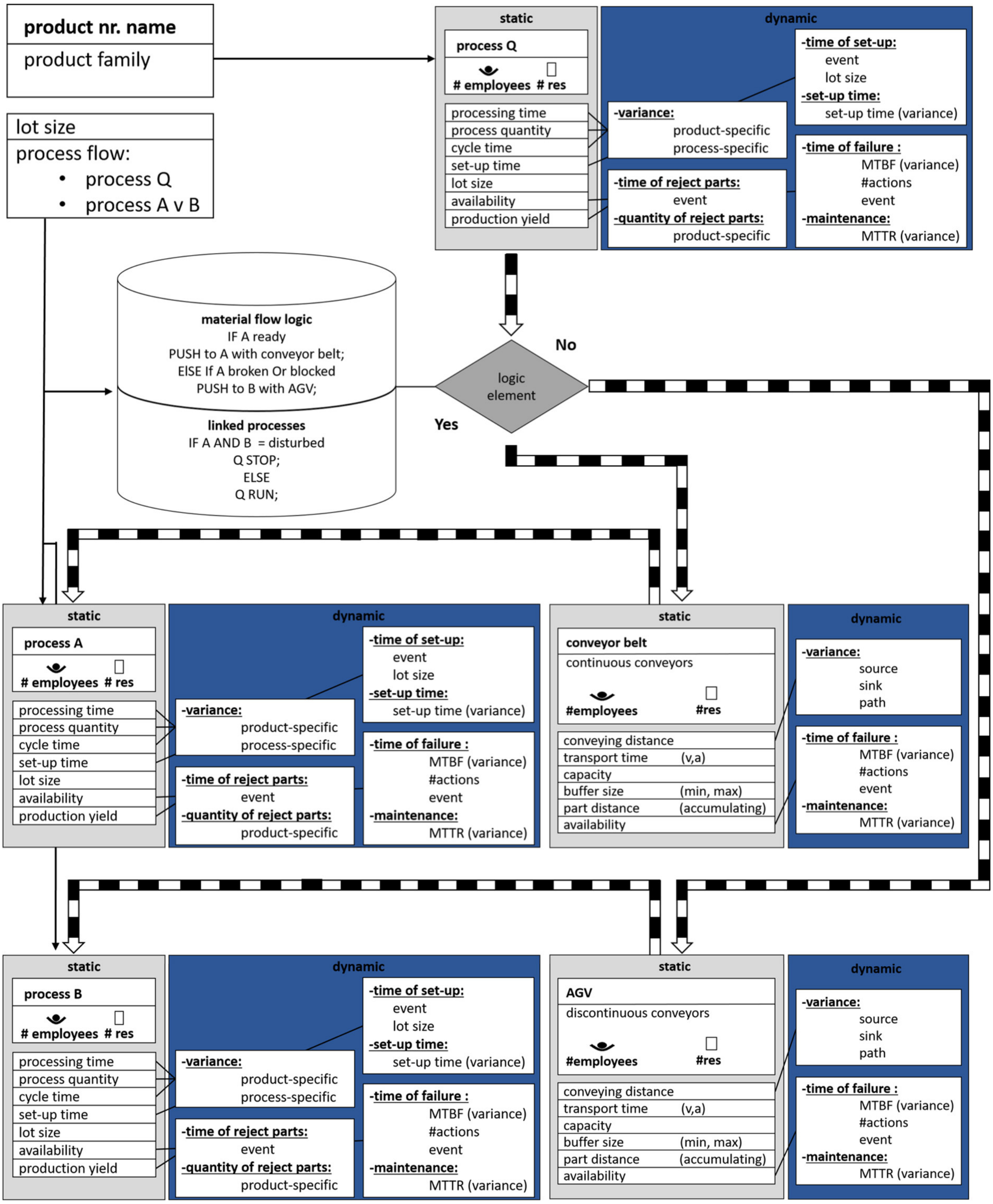

Figure 13: How a simulation with the RM based on value stream simulation would look like

6. CONCLUSION AND OUTLOOK

Establishing simulation in the bidding phase is a notable improvement for companies planning production systems with complex material flow systems. Possible planning errors can be identified earlier, increasing the competitiveness. This forms the basis for a secure and correct planning as well as for an exact offer preparation.

An important approach is that the modelling effort and the associated lead time of the offer creation have to remain low. The VSM enables a transparent and clear representation of all production processes required for the production of a product, in combination with the corresponding material and information flows (Erlach, 2010). The simulation enables an exact representation of dynamic systems in the value stream (Gutenschwager et al., 2017). This motivated the idea of combing VSM and simulation. The disadvantages of the simulation are the high modelling effort as well as the intensive resource requirement, which is reduced to an acceptable level with a value-stream-specific reference model.

The reference model, based on the value stream simulation, should not differ in the main features of its application from the conventional static VSM. For the construction of the reference model, the basic elements of the VSM are analysed and extended by dynamic aspects.

The level of detail of the reference model, especially for depicting the material flow logic, and its cost-benefit evaluation are going to be discussed in further research.

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