# Examining the PASS Approach to Process Modelling for Digitalised Manufacturing

## Results from Three Industry Case Studies

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Abstract. *This article investigates whether an existing process modelling notation - the Parallel Activity Specification Scheme (PASS) - can support the digitalisation of manufacturing processes. In particular, four aspects are examined that have previously been claimed to be benefits of the PASS notation: ease of modelling, distributed modelling, incremental change, and IT integration. This is done by analysing three digital transformation projects in the manufacturing industry. The projects included the analysis and improvement of cross-department value streams, the introduction of Automated Guided Vehicles (AGVs) on the shopfloor, and the specification of a new Manufacturing Execution System (MES). The ways in which PASS was used and whether it was able to provide its claimed benefits are presented and analysed.*

Keywords. Graphical Process Modelling • Subject-Orientation • S-BPM • PASS • Digitalization • Manufacturing

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## 1 Introduction

One of the earliest accounts of graphical process modelling is an article from 1921 by Frank and Lillian Gilbreth presented at the Annual Meeting of the American Society of Mechanical Engineers (Gilbreth and Gilbreth 1921). Back then, process modelling was intended and used as a design concept for mechanical devices and as an analysis tool for production processes. Nowadays, one could get the impression that process models are predominantly used in the domains of IT and business process management. However, in times of digitalisation, Industry 4.0, and increased automation using IoT technologies, there is increased pressure on the manufacturing industry to make their processes more flexible. In turn, this requires tools that help to understand, communicate about, and improve production and service processes, and often to create or configure IT systems supporting process execution. Graphical process modelling is a common method to support such endeavours.

Various approaches and languages for process modelling have emerged over the last few decades. One of them is the Parallel Activity Specification Schema (PASS), originating from distributed automation systems. It is based on a communication-centric paradigm that views processes as loosely coupled interactions of participants' behaviours rather than as global control flows. According to the proponents of this approach, there are a number of benefits compared to other process modelling notations. They include (Kannengiesser and Müller 2018):

- ease of modelling
- support for distributed modelling (i. e., multiple

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modellers that are not co-located in time and space)

- support for incremental changes of process models
- seamless IT integration

Yet, there is little empirical evidence for these claims, except for a few studies in academia (Moattar 2016; Singer and Zinser 2009). In this article, three industry projects in which PASS was used for the digitalisation of manufacturing operations are reported and examined with respect to the claimed benefits. The first two projects were carried out between 2015 and 2019 at ENGEL AUSTRIA GmbH, a family-owned manufacturer for customer specific injection-moulding machines with 6500 employees worldwide. The third project is being carried out at the time of writing at Peneder Bau-Elemente GmbH, a family-owned company that offers building solutions and fire protection elements and has 360 employees internationally.

The paper is structured as follows: Sect. 2 describes the fundamentals of the PASS approach, its distinguishing features and claimed benefits with respect to other graphical process modelling approaches. The three case studies are presented in Sect. 3, 4 and 5, respectively. The extent to which PASS provided the claimed benefits in the case studies are discussed in Sect. 6. A summary of the article is provided in Sect. 7.

## 2 The PASS Approach

### 2.1 Fundamentals of PASS

PASS (Parallel Activity Specification Schema) is a graphical process modelling notation that supports the paradigm of "subject-orientation".[1] Subject-orientation, as described by Elstermann (2019), Fleischmann et al. (2012), and Fleischmann (1994), requires a modeller to understand a process as a system of interacting entities and to express their existence as well as their interaction, respectively their communication. The interaction in form of messages must be described and named explicitly.

PASS process models consist of a *Subject Interaction Diagram (SID)* as shown e. g., in Fig. 9. These diagrams state who or which role/entity is involved in a process and what kind of messages are exchanged between those entities. These process entities are referred to as *subjects*[2] , while the data objects are captured as *messages*. Subjects are abstractions that represent human actors or technical systems. Messages can be physical objects (e. g., material in a production process), but they can also represent abstract or digital information exchange via computer systems (e. g., an e-mail or digital sensor data).

Every subject has a *Subject Behaviour Diagram (SBD)* that depicts the actions and interactions of that subject in the process — a subject's individual viewpoint of a process. SBDs are represented as state machines, such as depicted in Fig. 2, with three kinds of states: *Function states* that denote activities a subject does "on its own", *Send states* that denote sending messages to other subjects, and *Receive states* that denote receiving messages from other subjects. Transitions connect different states to specify their order of execution. Every transition has a condition that needs to be true for that transition to "fire". Alternative paths through a subject's behaviour can be modelled using multiple outgoing transitions of a state, each of which specifies a different condition. Parallel paths are not permitted within an SBD; however, parallel behaviour can be modelled using multiple subjects that are executed concurrently. Subjects coordinate their concurrent behaviours by exchanging messages.

For every message specified in a SID there must be a corresponding Send state in the SBD of the sending subject and a corresponding Receive state in the SBD of the receiving subject. A SID can

[1] Both terms, subject-orientation and PASS, are also closely related to the term of S-BPM — Subject-Oriented Business Process Management — referring to an overall process management approach where subject-orientation as a modelling paradigm and PASS as a graphic modelling language play a major role. Note that most research regarding subject-orientation can be found under the keyword S-BPM.

[2] The term of *subject* is used in a grammatical sense, not as a synonym for "topic"

thus be seen as specifying the agreed interfaces between subjects. When modelling a process using PASS, the typical approach is to begin with a SID representing an initial set of subjects and messages, and then model the SBDs of these subjects individually and constrained only by the messages to be sent and received as specified in the SID. Messages may be added, removed or modified when a new agreement can be achieved between the subjects involved (resulting in a modified SID). As a result, PASS projects often alternate between phases of collaborative modelling (i. e., creating or modifying the SID) and individual modelling (i. e., creating or modifying SBDs) (Oppl 2016).

The basic modelling concepts of PASS may be transferred to other process modelling approaches and modelled using their notations. For example, subject interactions may be represented using BPMN Choreography diagrams (Chinosi and Trombetta 2012; OMG 2013). However, their consistency with individual behaviour models (captured as Pools in BPMN Collaboration diagrams) would need to be enforced. In most BPMN practice, Collaboration diagrams are the predominant type of model. Choreography diagrams tend to be created rather as an afterthought, aiming to provide a more condensed view of a process already modelled in a Collaboration diagram. This is different in projects using PASS, where an SID is typically produced as the initial modelling artefact.

## 2.2 Claimed Benefits of PASS

Proponents of PASS claim that this approach has a number of benefits compared to other process modelling languages. They include ease of modelling, distributed modelling, incremental change, and IT integration (Kannengiesser and Müller 2018).

*Ease of modelling*: Modelling with PASS is claimed to be relatively easy compared to other modelling approaches, based on the small number of modelling elements and the "first-person" view afforded by the notion of subjects (Kannengiesser and Müller 2018). When a stakeholder owns a single subject, modelling the corresponding SBD can be done egocentrically by answering the questions: What do I need? (i. e., Receive states) What do I do? (i. e., Function states) What do I provide? (i. e., Send states).

Easily understanding and modelling is required for making the best use of the knowledge available within a company. Already the Gilbreths suggested that *"[t]he aim of the process chart is to represent information regarding existing and proposed processes in such a simple form that such information can become available to and usable by the greatest number of people in an organisation before any changes whatever are actually made, so that the special knowledge and suggestions of those in positions of minor importance can be fully utilized."* (Gilbreth and Gilbreth 1921) Domain experts typically have no expertise in process modelling; in turn, process modelling experts usually have no domain knowledge (Dumas et al. 2018). Proponents of PASS claim that, thanks to the simplicity of PASS, domain experts can be more actively involved in process modelling, leading to models that more accurately represent an organisation's processes (Fleischmann et al. 2012).

Simplicity in process modelling may also facilitate dynamic adaptations of processes to be more responsive to contextual changes, which play an important role for digital transformation (Baiyere et al. 2020). In contrast to declarative approaches that aim to provide this flexibility using complex formalisms (Pesic and Aalst 2006), PASS relies on process participants being able to rapidly change their graphical models as the need arises.

*Distributed modelling*: The encapsulation of subject behaviours, which are loosely coupled via message flows, allows partitioning large process models into smaller pieces. This has been suggested to have two advantages (Kannengiesser and Müller 2018): Firstly, stakeholders can focus on those parts of the process that they are interested in. Secondly, sub-processes can be modelled largely independently of one another, allowing concurrent modelling of multiple sub-processes and thus reducing the overall modelling time (Elstermannn

2019). This approach differs from current practices where processes are modelled by co-locating all participants in the same workshop. The "workshop" approach has been identified as a major bottleneck in many process modelling projects (Nolte et al. 2016).

This is where PASS diverges from the view of process modelling held 100 years ago: *"Every detail of a process is more or less affected by every other detail; therefore the entire process must be presented in such a form that it can be visualised all at once before any changes are made in any of its subdivisions."* (Gilbreth and Gilbreth 1921) Implicit in this statement are the ideas of Taylorism and Fordism prevailing in that era, that processes should be composed of basic tasks tightly interconnected by sequence flow. The decentralised perspective underpinning PASS modelling seems to be better aligned with modern forms of process organisations based on the self-organisation of decentralised, autonomous work units.

*Incremental change*: Radical changes in organisations bear significant risks and can induce fear in stakeholders. Therefore, AS-IS processes ideally should be incrementally changed into TO-BE situations, and every increment needs to be assessed before proceeding with the next. The loose coupling of PASS process modules (i. e., subjects) is claimed to allow for the addition, deletion and reuse of subjects and messages across different increments of such a transformation.

Reusing and changing parts of a process diagram and creating and storing different process versions certainly requires basic software support. In combination with modular process models this leads to the replacement of more primitive diagramming – in the way described in the Gilbreths' 1921 article (*ibid.*), using paper forms and diapositives – by computational modelling. Unlike diagrams, modern digital models can be used and reused in more flexible ways.

*IT integration*: A key problem in most digitalisation projects, especially in industry 4.0, is the seamless interoperation of systems from different vendors. The communication-centric approach of PASS provides a suitable modelling abstraction for the processes and associated systems to be integrated, as it can capture the data exchange requirements for the technical interfaces to be developed. As conceptually envisioned by Elstermann and Ovtcharova (2019), PASS models can provide specifications for the implementation of interfaces between different IT systems. Recent work on cyber-physical production systems (CPPS) development has similarly used the PASS approach for defining executable test cases for black-box testing (Kannengiesser et al. 2020).

(Gilbreth and Gilbreth 1921) noted that *"[v]isualizing processes does not necessarily mean changing the processes"*. Although they could not foresee the advent of computers and how this would affect process modelling, their statement can be reinterpreted in the light of digital transformation: As long as a particular transformation suggested by TO-BE process models is not implemented in software, it will per definition not be digital and thus not be turned into reality. As a result, for successful digital transformation graphical process modelling needs to close the gap towards IT.

## 3 Case Study Methodology

The previous section presented the claimed benefits of PASS. The goal of this work is to examine whether these benefits can be confirmed for industrial applications of PASS. The three projects used as case studies were carried out prior to the authors' decision to write this article (with the exception of Project 3 that is still on-going). The first author was project leader and process modelling expert in all three of them. The use of PASS in the projects was motivated solely by his previous experience with the modelling approach and specifics of the business context, not by any research interest in validating benefits of PASS.

Although the projects were not set up explicitly for the research pursued in this article, they provide sufficient data and insights to examine the validity of the four PASS claims. The data was collected by the first author based on his interviews and modelling sessions with the involved stakeholders, and from process models and reports. This corresponds to first and third degree data sources, respectively (Lethbridge et al. 2005). Second degree sources, i. e., measures taken during project execution specifically for case study purposes, were not taken into account given the non-academic nature of the projects.

Care has been taken to report each of the projects in a comprehensive way. A uniform structure for the project reports has been chosen to provide readers with a good sense of what problems were to be solved, how PASS models were used, and what results were achieved. The information provided within this structure aims to meet common characteristics of case study reports (Runeson et al. 2009). Additional details of Projects 1 and 2 can be found in previous publications (Moser and Kannengiesser 2019; Moser and Ríha 2019). The reported project results include both the technical/economic achievements of the individual projects and the insights gained with respect to the claimed benefits of PASS. A summary of the insights regarding the benefits of PASS, together with a cross-case comparison, are described in the Discussion (Sect. 7).

## 4 Project 1: From Value Stream to Process Modelling

### 4.1 Problem to be solved

As ENGEL is a strongly customer-oriented company with a focus on flexibility and innovations, their general priorities lie in a constant effort to improve the processes to offer customer specified solutions with short delivery times and the highest possible quality. In 2016 the management board set the goal to decrease the lead time of the major components for injection moulding machines by at least 30% without increasing the production costs and while maintaining or even increasing process stability and quality. It was part of a bigger project to decrease overall delivery times by improving processes and utilising existing digital solutions more efficiently. A non-trivial endeavour, as the production of the main component was and still is a cross-company process that spans two production plants in different countries with different languages, several departments (e. g., disposition, production planning, production, etc.), dozens of involved process actors, and an IT environment — the component also comes in several variations.

To ensure a cost effective and timely implementation, the digitalisation strategy was to utilise existing (software) solutions as efficiently as possible and keep changes within the possibilities of the organisational structure. Also, with a given extremely narrow time frame for the project of only 10 weeks, this basically meant that changes to the existing processes had to be implemented in the existing organisation and IT environment. More disruptive measures for further improvements would need to be done in another context since they should be based on strategic decisions and require a lot of manpower, money, risk and time management, and a corresponding level of maturity of the organisational structure.

At the time of project launch, there was almost no explicit information regarding the overall process, the detailed process steps, or the involved process actors available. Therefore, the first step was the documentation of the AS-IS status to get as much knowledge as possible about the material and information flows, as well as all factors that can have an impact on the production process.

The only information available were the following: the main component is assembled using three sub-components (Product 1, Product 2, and Product 3), which are produced in two production plants and that the process is coordinated through production orders sent between these plants. Incoming orders are registered in the ERP of the respective plant and the resulting internal demand creates a production order with a corresponding delivery date. In case that the registration process takes longer than 2 working days (due to several different factors), the production order will not arrive in production on time, which in turn results in a delay of the delivery of the final component.

A first analysis revealed that approx. 95% of all orders sent between the factories arrived too late and could not be processed automatically.

These orders then had to be processed manually (time consuming) resulting in an internal delivery reliability of only 39%.

### 4.2 How (and why) PASS was used

Except for a rudimentary description of the material flow between the factories there was no explicit process information available. The next step was to document and analyse the production process. The initial choice for that approach was Value Stream Mapping (VSM), an established tool for graphical documentation and analysis of production processes in the company and in general ((Rother and Shook 2011); (Erlach 2010)).

For the initial Value Stream Analysis (VSA) a component was chosen that accounted for approx. 30% of the overall production volume, had the most complex working plans, and the highest overall lead time of the three considered product groups.

By following the material flow on the shop floor level across both factories, surveying classical KPIs (stock, production lead times, customer cycle, etc.), and interviewing the responsible employees, a Value Stream Map for the relevant product (called "Product 2") was created.

Using VSM, two weak points in the overall process were identified: the lack of production synchronisation and the non-optimised, mainly manual, order processing. However, the production synchronisation was directly linked to the respective production planning process. After a brief analysis of the planning process, it was concluded that long-lasting improvements were only possible by completely reorganising and restructuring the operations of the process planning department and changing the overall way of thinking. While necessary, this was not feasible in the timeframe of the project. The project effort was therefore concentrated on the ordering process and its optimisation potential as a "quick-win".

This provided the entry point for a comprehensive process survey, especially regarding the possibility to improve the existing information flow by decreasing manual input and increasing the degree of digitalisation.

The VSM method is often promoted in the literature and by consulting firms as a means to describe not only the material flow but also the information flow. However, the limits of VSM regarding the capture of information flow were reached early-on in this project. VSM was missing a lot of relevant process information to describe the overall process and information flows in detail, e. g.:

- limited knowledge of the overall process
- no detailed information about the interactions between the involved parties outside of the production
- no information about which steps in the process are automated and which steps are manual
- no concrete information about the transactions used in the ERP System (SAP/R3)
- no information about the timelines of the information flow
- no verification of the provided information

VSM is a useful tool for representing linear (i. e., non-iterative) production processes and material flow between process steps. As the processes at ENGEL were more complex and heavily relied on information flow, a different approach was necessary. Flowcharts, which were previously used at the company, did not provide a good alternative due to their sole focus on activity flow. While they provided good process overviews, they were not detailed enough for thorough process analyses. Attempts to use them in a more comprehensive manner regularly resulted in overwhelmingly large diagrams ("process tapestry") that were difficult to understand. The lack of transparent process descriptions had led to tedious implementations of IT solutions, preceded by weeks and months of development and testing phases.

With neither VSM nor flowcharts being suitable options, it was decided to use PASS for graphically describing the information flow to be analysed.

Through more refined personal interviews with the process participants, a detailed process documentation was created. The interviewees described what they were doing (i. e., their subject behaviour) while the process modelling expert simultaneously created the process using a PASS modelling editor. The interviewee was able to watch the creation of the process model on a large TV screen throughout the session. The “Send” and “Receive” states of a SBD directly describe interactions between the current subject and other involved subjects. Based on these interactions it was possible to gradually add more subjects to the SID. The SBDs of the additional subjects were later modelled with the respective subject owners, using the same techniques of interviewing.

The resulting model of the AS-IS situation (sketched in Fig. 1) quickly emphasised the complexity of the logistics and production processes, with approx. 40 interacting subjects spread over the production of all three product groups. (The purpose of the figure is to give readers an impression of the size of the process model; the labelling within the SID is not relevant.) To distinguish between the two factories, the subjects were colour coded: green for Factory A and orange for Factory B. Further, those subjects were marked with shading to represent the different ERP system functionalities, to highlight the already digital parts of the existing process.

Although there is just one ERP system shared by both plants, for a more structured visualisation the system was split in accordance with the respective departments (SAP system A, SAP system B, and SAP system A Disposition). Because of the high number of involved subjects and the overall complexity of the process, it would not have been beneficial to survey and model all subject behaviours without a defined frame for the next steps. To define such a framework, the SID was used as a base to identify and analyse the central nodes and bottlenecks in the process.

The following results were found: The order of Product 1 through Factory A, the order processing and the acquisition of Product 2 through Factory B, and the production of Product 3 in Factory A involved up to 12 subjects (3 SAP Systems and 9 people) and took up to 15 working days (lead time). Also, only 65% of Product 2 were finished on-time because the order processing took too long and the orders arrived too late at the production centre (approx. 95% of all orders). This had a direct impact on the production of the main component (Product 1) and the overall process stability. The planned delivery times could only be achieved with lots of extra effort and troubleshooting in the production department.

The decision was made to focus on this material acquisition process - the logistics process (Blue Arrows in Fig. 1), because relative to the complexity of the provided Product 3 (raw material and components with a net value of a couple of Euros), the process itself was very complex and time-consuming.

With the SAP transactions clearly described in the SID and the employees SBDs, the project team was able to trace a dummy order through the system via the model. This allowed the team to recreate and visualise the various steps of the SAP-ERP system in its own SBD. Furthermore, the team was able to distinguish between digital and manual steps and to document the actual process lead times. As an example, Fig. 2 visualises the subject behaviour of one of the employees who handles the processing of production orders in factory B: The employee verifies if there are production plans available for planned production orders (the employee does not get an automatic notification). Then all planned production orders with available production plans are grouped using a defined, but not explicitly documented, set of rules and are then released for production. Several employees do this manually for every production order, with several thousand orders a day. For each production order manual input is required several times during the order processing. This accumulated to a workload of approx. 7 hours per day in total for Product 3 alone (simple raw materials and components).

The overall workload for the whole survey, all interviews, and the time needed to complete and verify the process models accumulates to approx. 200 performed person-hours. This is a relatively small effort compared to past process surveys, given the complexity of the process models, and the level of detail.

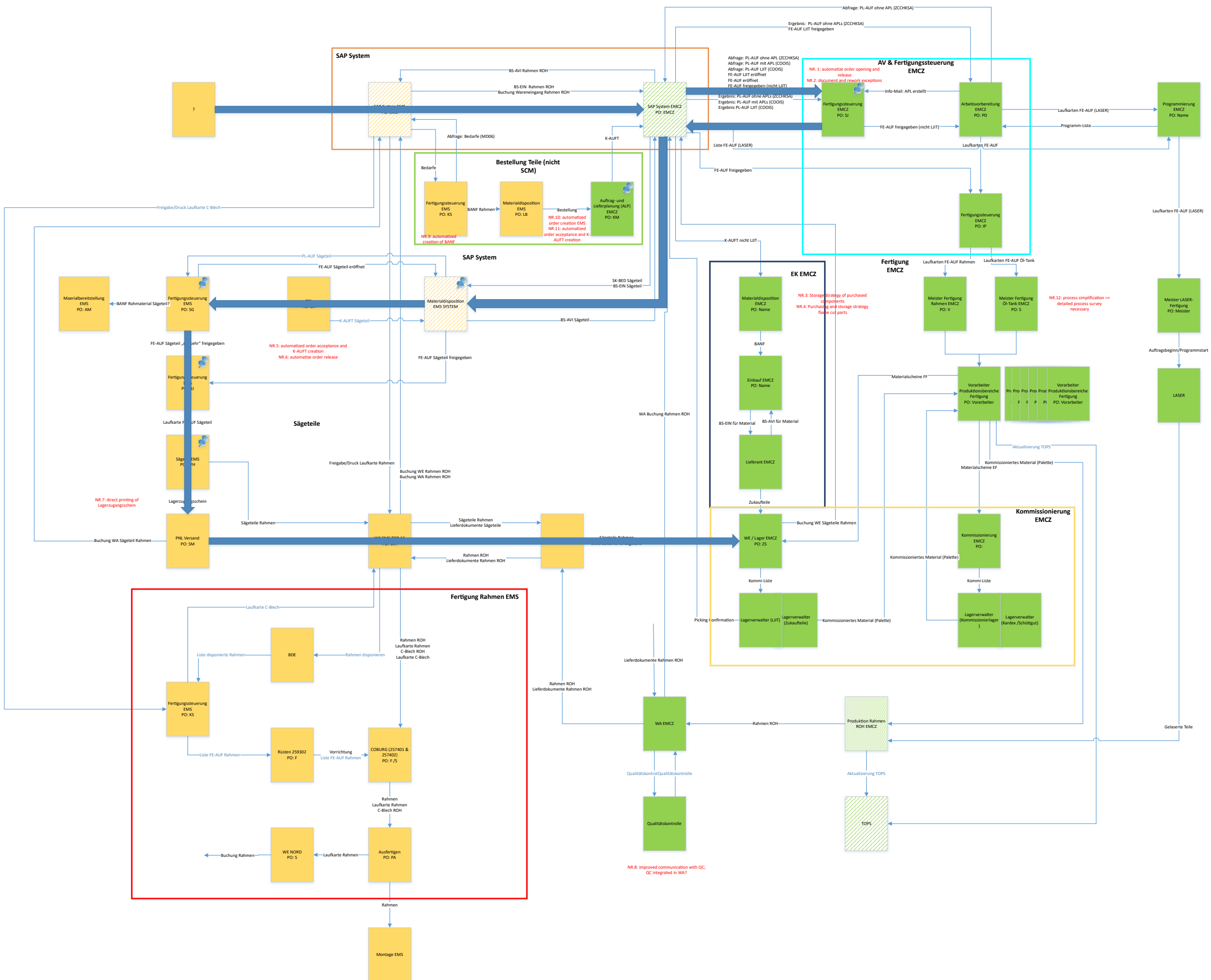


*Figure 1: Sketch of the AS-IS Process System SID in Project 1. The blue arrows show the path of the material acquisition process.*

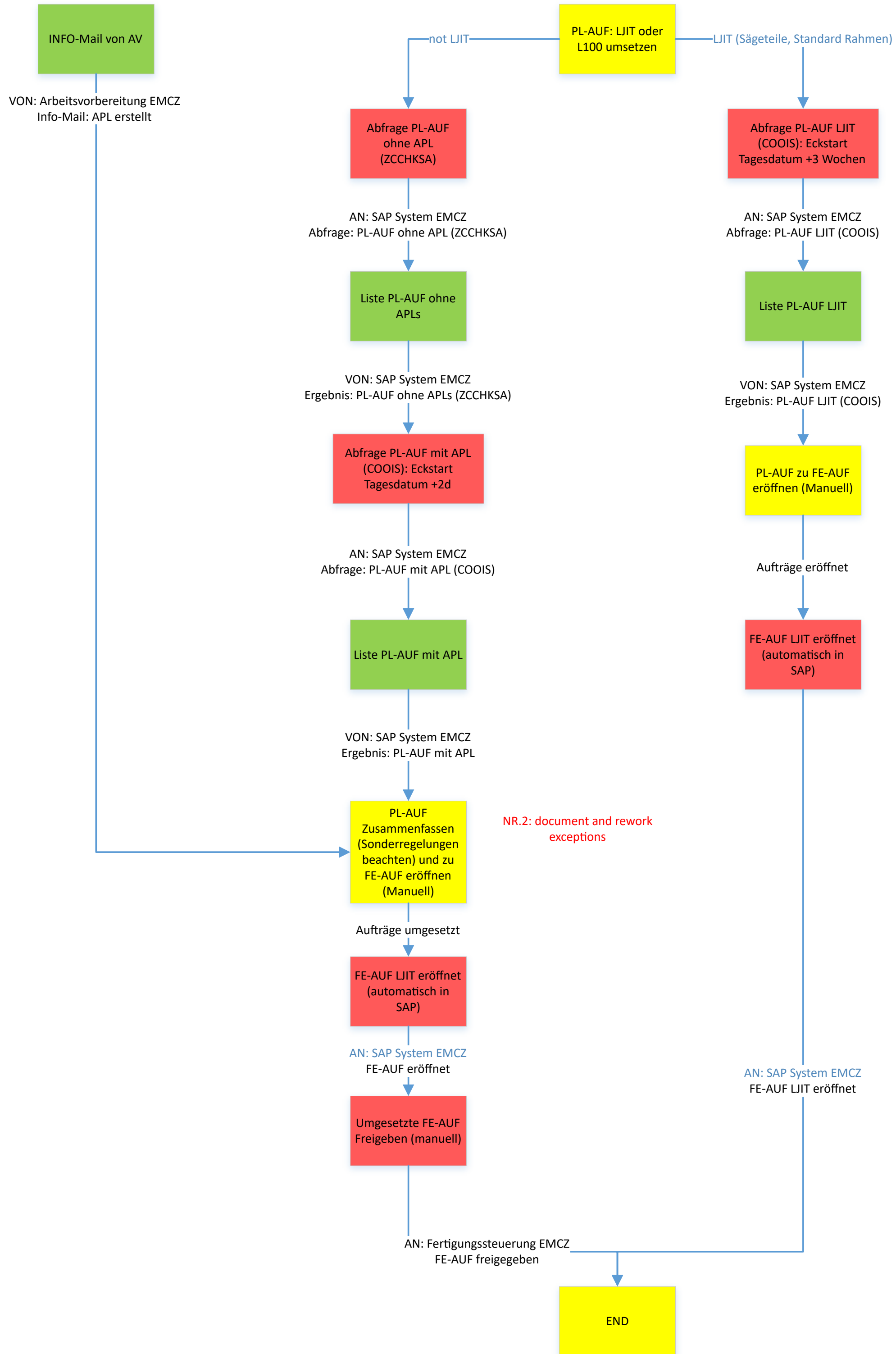


*Figure 2: SBD of employee handling order processing in factory B. Send states, Receive states and Function states are represented in red, green and yellow colour, respectively.*

### 4.3 Results

In collaboration with the employees and with the PASS models as the main tool, the existing working plans were reworked, updated and improved. This led to updated and reduced lead times for the working steps, as well as a reduced number of working steps by merging existing ones. In this case, a reduced number of working steps meant fewer subjects as well as fewer behavioural states in the process (model). This directly translated to fewer people involved in the process and less work for the remaining — a leaner process.

During the process analysis several similar process steps were identified that were carried out differently in the two factories. Additionally, existing automated SAP batch jobs were disrupted because required manual input was missing between steps. Such disruptions could occur several times for each order, which in the end could result in a delay of several workdays. After synchronising and automating these processes the disruptions because of missing manual input could be reduced, leading to a faster processing of orders, production planning and shipping.

Measured results:

- Order Processing:
  - Down to 2 days (from 5–10)
  - Increased process stability and quality: reduction of initially 95% of orders registered too late down to 12%.
  - Reduced manual workload by approx. 5–6 hours per day to one hour per day.
- Raw components: Product 3:
  - Production and shipping process down to 3 days (from approx. 5–6 days)
  - Overall lead time reduced by app. 87% to 2 working days.
  - Increased delivery reliability to app. 89% after four weeks of the implementation and to 97% after one year.
- Assembly: Product 2
  - Production and ordering process down to 12–14 days (from 19–23 days)
- Main component: Product 1
  - Reduced overall lead time down to 18–20 working days from 26–33 working days
  - Overall reduction of approx. 45% for the whole ordering and production process, surpassing the initial goal of 30% reduction.

Another result was a new warehousing strategy and the implementation of a digital KANBAN (e-KANBAN) system for critical parts required to produce Product 3. Simultaneously, stock of non-critical parts could be reduced, further freeing space in the warehouse.

After these changes, all required components were available within one workday, either by internal direct delivery or through a safety stock at the supplier. This was a significant improvement in process stability and reduction of the work-in-process components for a comparatively small increase in stock value, where previously interruptions of production (due to missing components) could take up to 15 workdays.

*Ease of modelling*:

The small number of symbols of the PASS Notation enabled process participants to understand the notation after only a 10-minute introduction. That introduction mainly focused on understanding and creating SBDs, so that process participants were able to articulate the process from their own point of view (i. e., only their own subject). The goal was to enable them to structure their SBDs around the three key issues: *“What do I need from others?”* (Receive), *“What do others need from me?”* (Send), and *“What do i need to do?”*(Do). SBDs of other subjects were disclosed only upon request, in order to keep the mental overhead for stakeholders at a minimum.

The combined interviewing and modelling enabled process participants to create a direct reference between their mental model of the process and the PASS model. This also reduced the post-interview documentation effort because the process models were the direct result of the

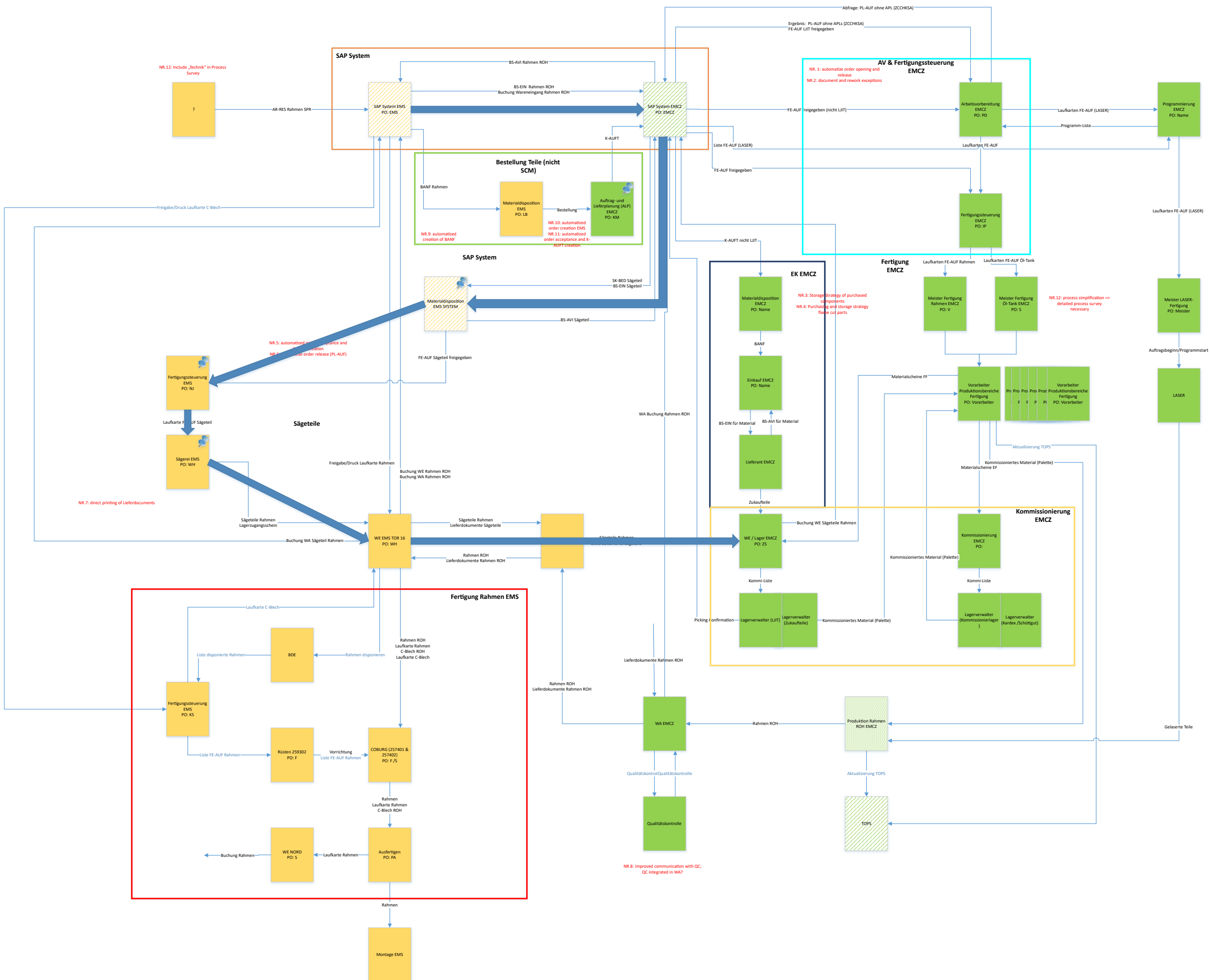


*Figure 3: Sketch of the TO-BE Process System SID in Project 1. The blue arrows show new the path of the material acquisition process.*

interviews. No intermediary textual description was required. During the interviews the process participants began to (verbally) verify and correct the model by themselves. This can be seen as a confirmation that the short introduction to PASS was sufficient to understand and contribute to the process models.

*Distributed modelling*:

Every interview involved modelling the behaviour of only those subjects that the respective interviewee was responsible for. This was a great advantage for project management, individual interviews were easier to be scheduled than collaborative workshops involving participants from multiple countries. The one-on-one interviews also led to a more efficient modelling process because they eliminated the idle time of process participants not involved in the current process part. These factors also increased the overall motivation and acceptance of the participants regarding the process survey and modelling.

On the other hand, a disadvantage of this approach was that it was difficult to understand the overall chronological order of the process over all subjects and messages in the resulting SID without very deep and specific knowledge of the whole process. One can mitigate this to some degree by attempting to lay out the subjects in a chronological order. However, this is only possible for SIDs with small numbers of subjects and loops. For better understanding the overall process, the PASS model was translated into a (slimmed down) swimlane diagram to visualise the chronological order.

It was also observed that a large number of subjects and messages reduces the readability of process models. The arrows representing the messages become difficult to track in terms of their direction (i. e., from/to) and content. Based on former applications of PASS a uniform convention for labelling subjects and messages was established: Subjects are given a name and a unique number, and messages are given a name with a prefix describing their source and sink (e. g., "02_03 MessageName" for a Message from "02_Subject" to "03_Subject").

*Incremental change*:

Throughout the project, the process models had to be expanded, revised, and corrected a number of times. Previous model versions were not discarded but merely modified and saved as new versions, consistent with the idea of incremental change. Changes to describe the TO-BE state were visualised by adding or removing individual subjects, subject behaviours or messages. The effort involved in these modifications was relatively low.

*IT integration*:

The documented process models described concretely defined processes, including all the relevant process steps in the SAP system, all the required SAP transactions, and the interaction between the system and employees. The detailed graphical process description allowed the IT department to directly implement the new processes, rework the existing processes, and streamline the processing schedule of existing batch jobs for both factories. These implementations in the existing system environment were done within only one working week (to the surprise of top-level management) and by only one IT specialist (approx. 38 work hours). This included process steps such as order acceptance, order opening, order release in both plants, and delivery of the order papers to production within the ERP System. As mentioned before, the automatic order processing allowed for order-related and timely processing of the products.

## 5 Project 2: Integrating AGV Technology

The second digitalisation project at ENGEL Austria GmbH was concerned with the introduction of a new internal logistics system based on automated guided vehicles (AGVs).

### 5.1 Problem to be solved

The many levels of manufacturing were coordinated and planned by an existing Manufacturing Execution System (MES). Internal logistics transported the necessary raw materials and semi-finished products through the various shop floors, operated in four shifts.

In late 2018 the company started a pilot project to introduce Automated Guided Vehicles (AGVs) with the goal to support the internal logistics and ease the workload of forklift drivers for standardised transport units. The implementation of AGVs in the production plant was considered a high-risk investment for ENGEL because of the initial high cost of AGVs and the production-critical nature of the internal logistics. To reduce the risk of the pilot project, it was deemed necessary to implement AGVs through a series of small steps that can easily be validated, expanded or if necessary reversed. At the start of the project there was no explicit process documentation of the relevant logistics processes available. Therefore, the AS-IS processes of the internal logistics had to be documented to provide a basis for the definition of future TO-BE processes and the steps required to transfer to the new state.

The goal was to document the processes at every stage of the project in a way that was comprehensible for the whole project team. That team consisted of internal logistics planners, machine operators, forklift drivers, IT staff, and the external suppliers of ENGEL's MES and AGVs. However, due to differences in the team members' work environments, jargons, training and experience, constructing a shared understanding about the processes would be a challenge.

## 5.2 How PASS was used

Based on the positive experiences gained from using PASS in Project 1, the same modelling language was chosen in this project. PASS models were used to survey the AS-IS situation and to iteratively develop models for the multiple TO-BE stages in the transformation from an initial, largely human-operated system towards a highly automated AGV system. The same interviewing and modelling techniques were used as in Project 1 to elicit the individual SBDs of the subjects defined in the SID. Whenever it turned out during the interviews that additional subjects were needed, they were added to the SID and interviews with the respective process participants were scheduled to model their SBDs.

*Stage 0: Modelling the AS-IS process*

As stated, the goal of the initial project stage (Stage 0) was to survey and document the AS-IS process of the internal production logistics to establish a common understanding of the process. The SID of stage 0 is shown in Fig. 4 (labels in the SID are not relevant for this article). The process could then be analysed by the project team to identify possible improvements regarding AGV support and the projected overall benefit of such a system.

Based on the SID, several areas of improvement were identified by automating and digitalising parts of the process. One special area concerned the available transportation capacities (i. e., the forklift drivers). They were predominantly occupied with "simple" transportation orders dealing with standardised euro pallets or individual small parts. However, forklift drivers are most effective when carrying out more difficult transportation tasks involving oversized (up to several meters in length) and heavy weight materials (several thousand kilograms). Every time a small part (individual parts of up to 15 kg) is transported by a forklift (designed to carry loads of more than 1,500kg), there is a clear waste of transportation capacity. A fact emphasised by the forklift drivers themselves. Also, the manual prioritisation of transportation tasks was a source of errors causing production delays. For example, the high number of transportation orders made it difficult for the forklift drivers to correctly apply the rules for prioritisation. The drivers were not notified of any changes in production orders that affected the sequence of transportation orders. In addition, the communication with the workplace operators was ad-hoc, sometimes causing storage overflows of finished production orders at the workplaces.

Based on these findings and a detailed cost-benefit analysis, the process to introduce AGVs was green-lit, in order to take over all standardised transportation tasks in the long term, app. 80% of all internal transports. The project team then used the process model as basis to define possible implementation scenarios and to communicate

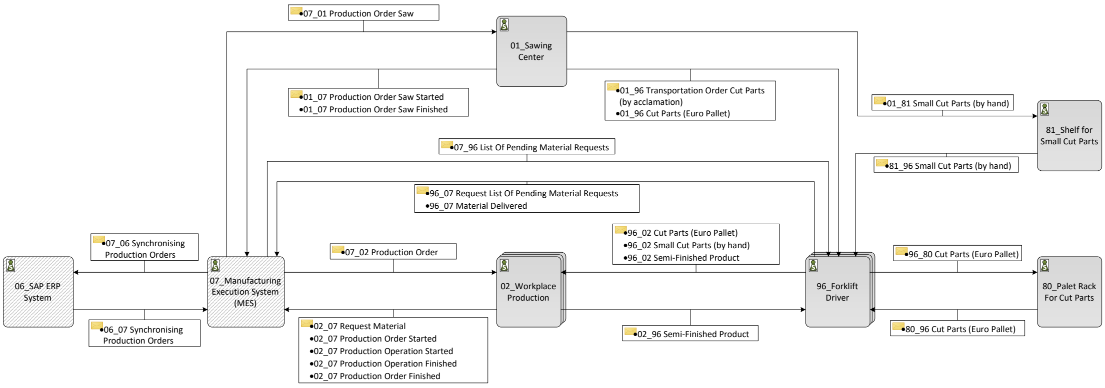


*Figure 4: SID for the AS-IS situation before introducing AGVs in Project 2*

the resulting requirements with the possible AGV suppliers.

A pilot project was then set up to realise and validate the process changes over three following stages:

*Stage 1: Automated Guided Vehicle for Small Loads*

In stage 1, the goal was to introduce AGVs on the shop floor for the transportation of small parts and selected workstations. The AS-IS process model was adapted to visualise planned and required changes in the transportation process and corresponding systems. For a better overview of the changes with respect to the AS-IS model, they were highlighted using different colours (green for additions, red for deletions) (see Fig. 5) (labels in the SID are not relevant for this article).

While possible in principle, automation of loading and unloading would have been a too cost intensive investing. Therefore, in the first implementation step manual loading and unloading was implemented, where human station operators execute the loading tasks and confirm them by pressing a button.

Based on that, the first running AGV system was then actually introduced.

During this stage practical experiences regarding the integration of AGVs in a running production were gained; specifically, related to the workers' acceptance of new technology, order handling, route design, system integration and process stability.

*Stage 2: Storage Location Management and Automated Guided Vehicle for Large Loads*

Stage 2 introduced the transportation of raw material for larger parts between selected working stations. Again, the changes were depicted in the process model and the model extensively used to communicate within the project team and other affected areas. The most important part was the verification of the intended process with all affected employees of the logistics and production departments. The main questions that had to be answered were simple and difficult at the same time: *Do you and your work benefit from this new process?* This was especially important in stage 2 because of the resulting deep and far-reaching changes regarding the logistics transportation process. Here the graphical process model proved to be invaluable as a “common language” for communication between all involved parties and the project team.

*Stage 3: Automated Creation of Transport Orders*

Finally, in stage 3 the AGV system was connected to the existing MES in order to automatically create and manage transportation orders whenever a production step is finished and the material or the semi-finished product is required

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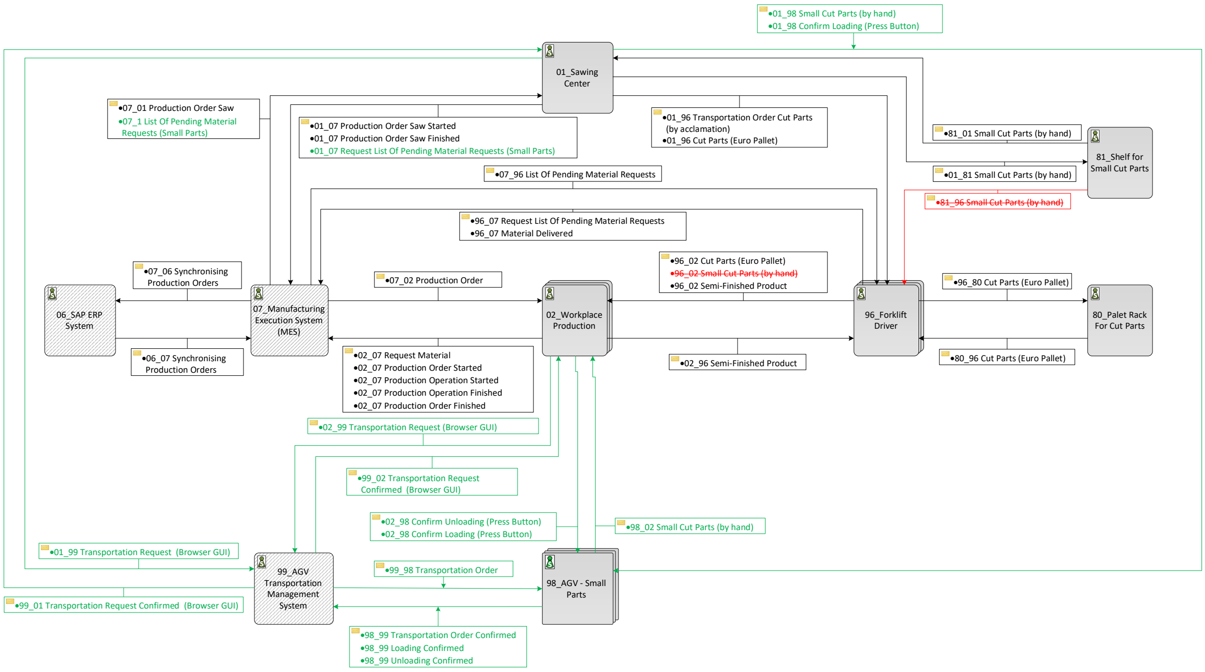


*Figure 5: SID of the TO-BE transportation process after implementing the AGV (Stage 1)*

at another workstation. In a best-case scenario this means that no more manual forklift drivers are needed for the transportation of material between the selected working stations. If, for some reason, one of the target stations is not included in the infrastructure of the AGV, the transportation order is automatically sent to the forklift drivers via the MES.

The changes to the previous stage were first planned and discussed using a PASS process model, with colour-coding to highlight added or removed subject or messages. The effort for the creation and analysis of the process models across all project stages accumulated to approx. 160 person-hours.

## 5.3 Results

Stages 1 and 2 are implemented and operational[3] .

*Ease of modelling*:

All involved process actors were able to quickly learn the notation and to understand and contribute to the process models independently of their background (from IT specialists to forklift drivers). One of the principal tools for implementing this strategy was the application of PASS that creates a common project language to describe the information flow between process participants and its support for creating modular process structures.

*Distributed modelling*:

Changes across project stages did not require creating a completely new process model from scratch. The loose coupling between subjects enabled reusing the same subject interaction diagram with smaller changes by adding or deleting individual process elements. Subject behaviours are encapsulated within their respective subjects, and one does not need to know the SBD at all to be able to model the subject interactions. This made it possible to describe the process without knowing what every subject does in detail. For example, it was not necessary (nor possible) to describe what the subject “AGV Transportation Management System” (see Fig. 5) is doing, but it

[3] A demonstration can be seen at: https://www.youtube.com/watch?v=Mpds0goQpzo&t=8s. The success story was published by the AGV solution provider (DS Automotion 2020)

was possible to describe the interactions with the system and the information these interactions have to convey, which was the basis for the specification of system interfaces.

*Incremental change*:

The relatively fast and simple visualisation of the possible project stages and the required changes further helped to communicate necessary changes and requirements internally and externally. This saved time and effort in planning and validating the process changes in every increment of the project. In addition, it was possible to better estimate the implementation cost for each project stage.

Further detailed data and process analysis, based on experiences from stage 1 and 2, showed that far-reaching and complex changes to existing data structures within the ERP system would have been necessary to reach the initially requested level of automation (stage 3). The very high implementation cost resulted in a non-acceptable amortisation time. At the time of writing of this article (July 2021) the implementation of stage 3 is therefore suspended. This shows that the incremental strategy used to reduce the involved risks of the transformation has proven to be successful.

*IT integration*:

The PASS models proved to be a successful means for communication within the project team. This facilitated the elicitation and communication of requirements for the development of human-to-machine and machine-to-machine interfaces. The process model was used to communicate specifications and requirements with the AGV supplier. In addition, the model was used for verification of the concept before implementation.

## 6 Project 3: Specification of an MES

In early 2020 Peneder Bau-Elemente GmbH began an extensive programme to identify and implement improvements in all planning, logistics, and production processes for its fire protection elements. This was based on the strategic goal to modernise the company, increase resource efficiency, and ensure the envisioned company growth. Over several months of analysis, many potential improvements with varying scopes of implementation effort were identified.

The improvement that was deemed the most beneficial but also the most complex and comprehensive was the digitalisation of the entire production system by introducing a Manufacturing Execution System (MES). Consequently, a project team was created with the goal to digitalise production and all associated processes (e. g., production data acquisition, machine data logging, production and capacity planning, material management, logistics, etc.) and thus to create a more structured, lean, and transparent work environment. The team set out to define the system requirements, followed by choosing an appropriate software supplier and finally implementing the software solution.

### 6.1 Problem to be solved

The introduction of an MES is a resource-intensive change with far-reaching consequences for all areas in a company. Switching between different MES solutions cannot be done easily and the implemented system has to be operational for decades. The introduction of the MES in this project was required to work in two ways: The MES would have to integrate in some of the existing processes, while other existing processes would have to be changed to fit into the new digital MES environment. This was taken as an opportunity to also identify and realise necessary process changes.

To determine the correct requirements and create good specifications for a new system, it is necessary to have detailed knowledge and understanding of all relevant processes and interfaces between software, production machines, and personnel. However, in the beginning no explicit or up-to-date process documentation was available. Similar to project 2, the project team was divers and consisted of shopfloor team leaders, IT consultants, production planners, quality management, etc. Again, a common language to ensure common understanding was needed, prompting the utilisation of subject-oriented process modelling with PASS.

### 6.2 How PASS was used

Like in the previous projects the process participants were interviewed one-by-one. The model and the modelling process were displayed on a big screen for all attendants.

The created process models were used to achieve a common process understanding and to define the interfaces between shopfloor workers, production machines, software applications (custom-built and COTS), ERP, machine sensors, and product track & trace. During process elicitation, any required or desired changes to the processes were directly incorporated in the process models. This meant that the AS-IS processes were not documented and analysed separately before adding improvements. Instead, TO-BE processes were directly modelled from the start. This was unplanned, and happened because during the elicitation stage the interviewees articulated not only their daily way of working but also very detailed requests for changes that would improve their work. As many of these requests were related to the use of the new MES, it was decided to directly model the TO-BE processes accordingly. During the initial survey and modelling phase, process models were created for every area as a whole (i. e., logistics, metal sheet production, powder coating, etc.), because this was the natural way the team leaders described their departments. They described their work as one ongoing process from start to finish and did not break it down into individual sub-processes. The resulting process model (consisting of several area-specific SIDs) comprised over 80 subjects, almost as many subject behaviours, and several hundred messages exchanged between the subjects (for examples see Fig. 6 (labels in the SID are not relevant for this article), Fig. 7, and Fig. 8).

The MS Visio plug-in[4] used for modelling provided a direct export of the graphical process models into a textual process description that included a comprehensive list of all subjects, subject behaviours, messages, states and their corresponding descriptions. However, the overall documentation was overly detailed, over 140 A4 pages long, and therefore practically incomprehensible for anyone not deeply involved in the surveying and modelling process. Nonetheless, the textual documentation, in addition to the graphical models, helped identify relevant interfaces between the process actors. This was especially helpful with regards to the planned machine data logging (MDL), in particular, when describing in detail the individual machine control systems that were to be integrated into the MDL.

The resulting process models were used as a basis for generating a specification document to communicate interface requirements internally between production departments and IT as well as with the possible external software suppliers. While the process models directly contained the TO-BE process, the finished specification document additionally described the AS-IS situation in textual form. For a better understanding, specific MES functions were described by means of classical use cases. Based on these, function-specific process models were derived from the overall process models (See Fig. 9). The goal was to decompose the overly large process models into smaller, easily comprehensible process models that were then used as a basis for acceptance testing to verify the proper implementation with the MES supplier.

Overall, it took approx. 90 workhours over a time span of four months to survey and model the process and approx. 160 workhours to create the finalised specification document. This was quite fast, considering the large number of involved subjects, the level of detail of the models and the specification sheet, and the start from complete scratch.

### 6.3 Results

Manually generating the requested specification and requirements documents based on the process model turned out to be rather simple. The 45-pages document contained general goals and fundamental requirements for the overall process

[4] https://subjective-me.jimdofree.com/visio-modelling/

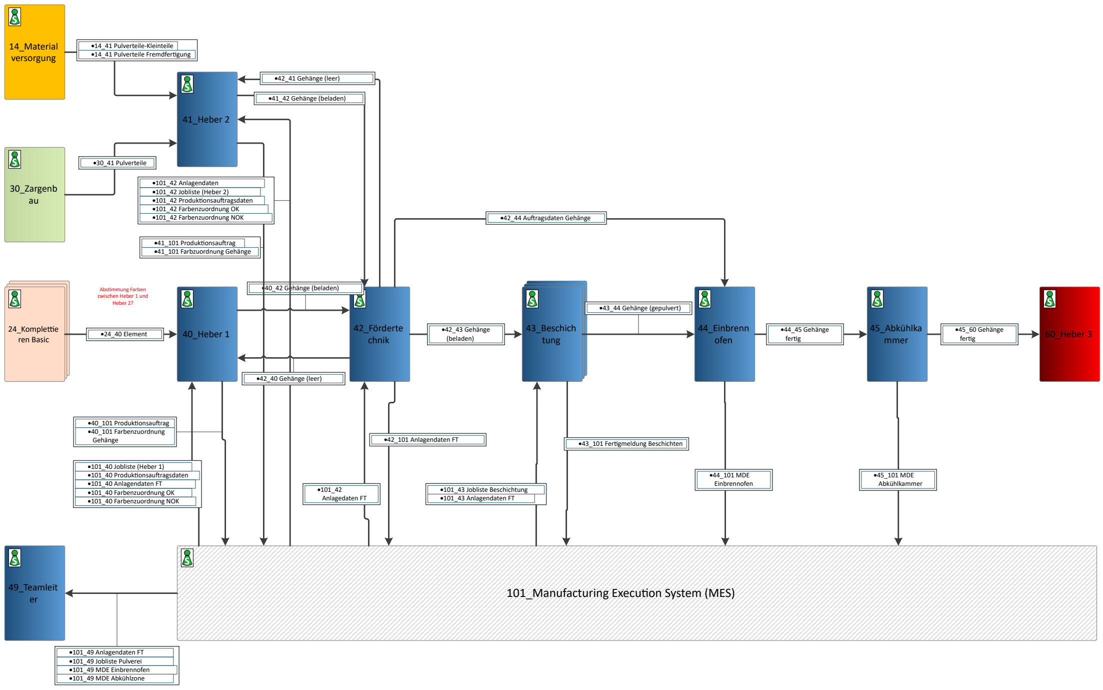


*Figure 6: Powder coating process (SID)*

as well as several use cases or user stories. While nominally different from the model, most of them are direct excerpts from behaviour diagrams. At the least, they refer to the graphical process model that is completely contained in the appendix to the document.

*Ease of modelling*:

None of the involved process participants (leaders of various production teams on the shopfloor) has had any previous experience with process modelling or process management. Similar to projects 1 and 2, the process participants were given a brief introduction to the PASS notation. The team leaders mainly described what they were doing during the process and the modelling expert was modelling it in parallel. All actors were able to read, interpret and verify the resulting process model and even began to describe their desired TO-BE process by changing the process model.

With the growing complexity of the process model the same problems as in previous projects arose: Reduced traceability of messages and chronological order. However, these issues were not as prevalent based on the very linear production process.

*Distributed modelling*:

Every area supervisor was interviewed individually because otherwise classic modelling workshops would have required the presence of all team leaders at the same time. As team leaders have to report their production and non-production hours (i. e., time worked on projects) this would have had a direct effect on the weekly factory reports. To reduce the process model and improve readability, the SID was decomposed into a set of partial SIDs representing sub-processes carried out by different production areas. The connections between the different sub-processes are established using so-called "interface subjects". An interface subject is a subject without a behaviour diagram and is used as a placeholder to represent other SIDs. Fig. 6 shows a production area (blue subjects) connected with four other areas through interface subjects coloured in orange, green, pink and red, respectively.

*Incremental change*:

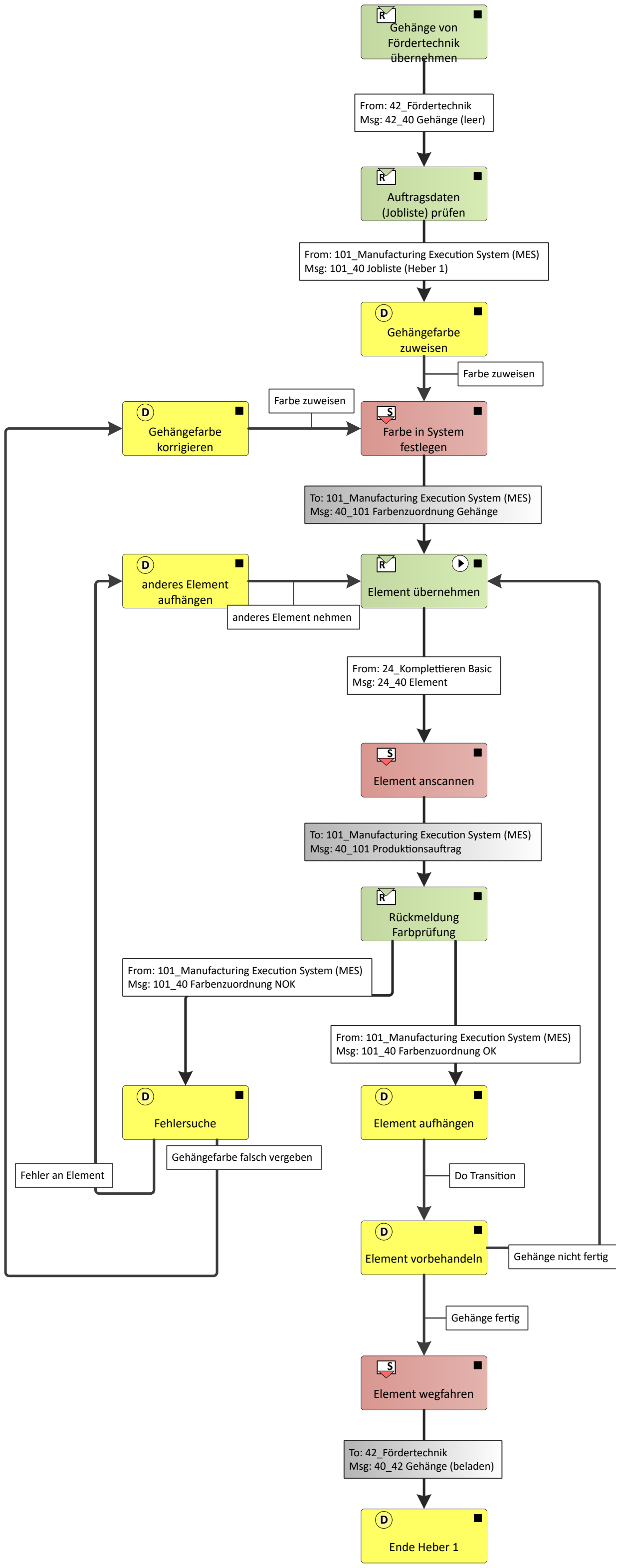


*Figure 7: Subject Behaviour Diagram of work station "Heber 1"*

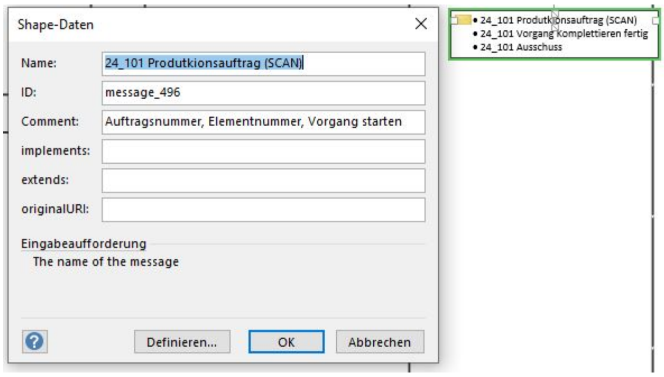


*Figure 8: Message "Production Order"*

Similar to Projects 1 and 2 the process models were modified a number of times during the modelling process, consistent with the idea of incremental change. Changes of the TO-BE process were visualised by adding or removing individual subjects, subject behaviours and/or messages.

To increase accessibility to the models for the suppliers in the specification only specific use cases (in terms of selected sub-processes of the overall process) were included. These sections were "cut out" of the overall SIDs by deleting non-required subjects, messages and states. It was not necessary to model these sections from scratch (Fig. 9).

*IT integration*:

The 140-page process description was not directly usable for all goals of the project. Although the models were found precise, well structured, and generally understandable, the intended software solution providers requested a more compact and traditional specification document for their bid. During an implementation session the contractor gave positive feedback to the project team regarding the level of detail and clarity of the process description. Data specifications (i. e., workstation structure, data hierarchy, ...) were discussed and defined in a number of short online workshops (up to 1 hour). Topics that, according to the software supplier, often took several person-days over a total period of several weeks with other customers to resolve. This made it possible to set up a first base system within a test environment only 4 weeks after the first technical workshop with the contractor, directly reducing project lead time and saving money (as the contractor charges per person-hour on the project).

## 7 Discussion

In this section, the results and insights gained from the case studies will be synthesised and discussed.

An overview of the modelling output and effort spent for each project is shown in Tab. 1. The output is based on the number of key element types used in the respective PASS models, i. e., subjects, messages and states. The effort includes the total time needed for eliciting, modelling, and verifying process models including data objects. It can be seen that there are significant differences between the individual projects: The relative effort (in terms of total time per model element) was significantly increased in Project 2. This is due to the fact that this project was quite disruptive and required multiple iterations. In contrast, Project 3 had the lowest relative effort. This may be explained by the close proximity of the involved departments and the increased experience of using the modelling approach from one project to another.

The particular usage of process modelling differed across the projects, covering analysis, improvement, and requirements specification. Yet, what all projects had in common was that the process models were ultimately created for documentation – the principal goal of most business

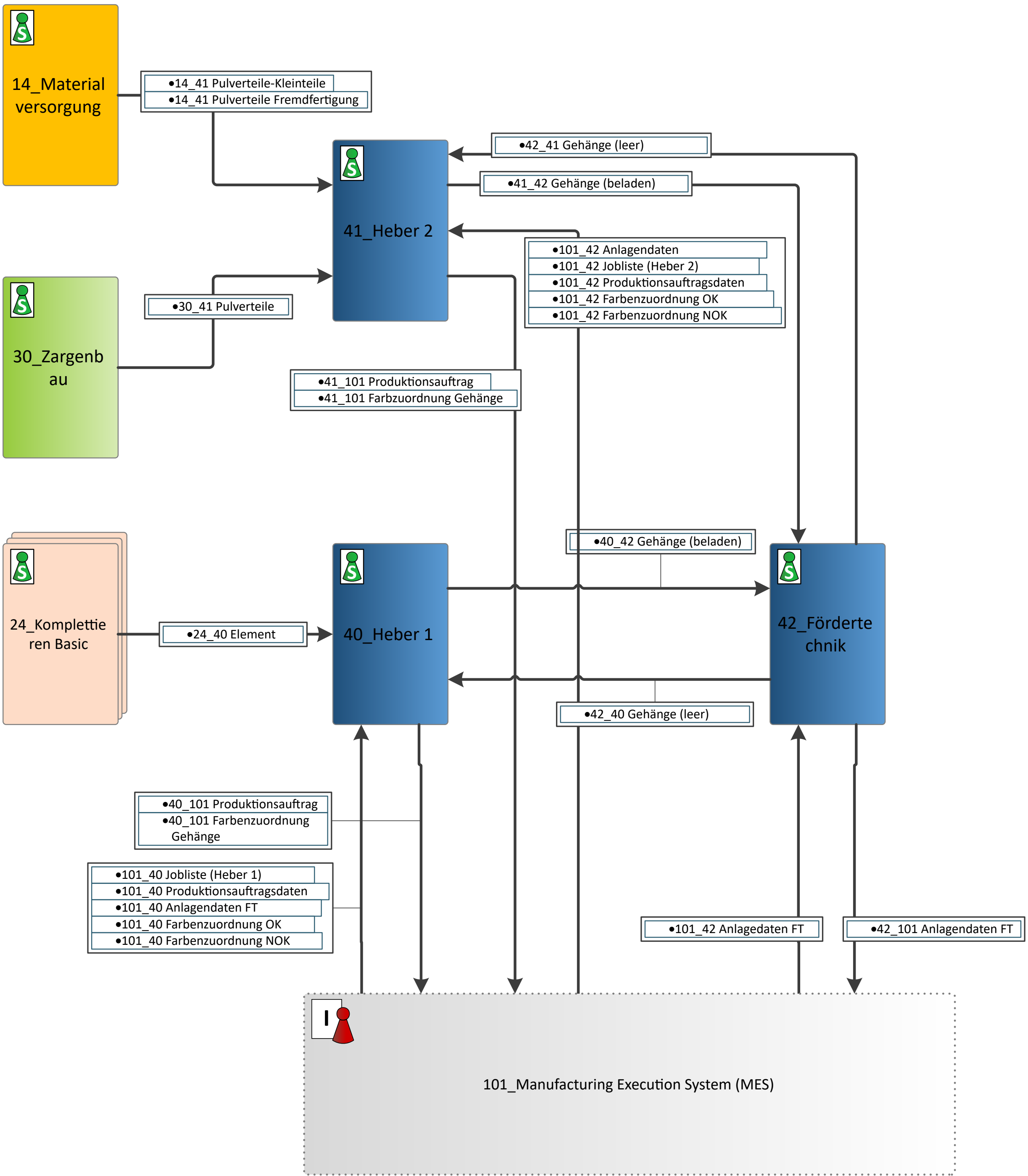


*Figure 9: Powder coating sub-process (SID)*

*Table 1: Process modelling output and effort for the three projects (P1, P2, P3)*

| | P1 | P2 | P3 | Total |
|---|---|---|---|---|
| **no. subjects** | 53 | 17 | 86 | **156** |
| **no. messages** | 108 | 67 | 278 | **453** |
| **no. states** | 103 | 12 | 229 | **344** |
| **Modelling time [person hours]** | 200 | 160 | 90 | **450** |
| **Total time per model element [person hours]** | 0.76 | 1.74 | 0.15 | **0.48** |

process modelling (Kocbek et al. 2015). Documenting is, generally, viewed as a burden that does not directly contribute to productivity. However, this was not observed in the three projects. Here, process modelling was used as an operational tool rather than a final "wrap-up". The PASS models created were used as living documents that constantly evolved, and their creation process was integral to understanding and structuring complex states of affairs. They represented central reference points for all stakeholders, not just at the end of a project or project phase but at any time throughout the lifetime of the projects.

The previous sections have shown how the claimed benefits of PASS could be confirmed, to a large extent, in the individual projects. They may have contributed to the use of process modelling as an operational tool throughout the project. We will summarise our observations regarding these benefits in the remainder of this section.

## 7.1 Ease of Modelling

In all projects it was a noticeable that process participants were able to easily understand, read, and describe PASS models. Only a few minutes were sufficient to introduce participants to the PASS notation, and productive work – i. e., defining actual or desired work routines as PASS models – began immediately after. This ease of learning and practising PASS modelling was observed for all stakeholders, independently of their individual domains and prior training. It appears obvious that this is due to the small number of symbols required for PASS modelling.

Another contributing factor might be the two-layer modelling structure of PASS, as it can deliver tailored views showing either a general overview (SID) or concrete process steps of a specific subject (SBD). Yet, it could also be observed that model understandability is limited for overly large and complex processes – which is recognised as a general problem in business process modelling (Dikici et al. 2018). Visualising process steps in a comprehensible, chronological order becomes more difficult the more subjects and loops in their behaviour are involved. It can be beneficial in some instances to complement PASS models with swimlane diagrams (such as in project 1) or similar visualisations.

## 7.2 Distributed Modelling

The visualisation of processes was often narrowed down to those subjects and behaviours that were relevant for specific process participants. This allowed modelling largely independently of other process participants within the boundaries set by the messages that needed to be sent or received. There was no need to align the different work schedules of multiple stakeholders. In addition, not all subjects had to be fully specified in terms of their internal behaviour.

Another feature of PASS that is likely to have contributed to the efficiency of process modelling is its support for readily decomposing large process models into sets of smaller sub-processes (see Project 3). This helped to avoid individual departments getting overwhelmed with having to understand the SID of the "end-to-end" process.

## 7.3 Incremental Change

An incremental approach was followed most explicitly in Project 2, where a separate version of the evolving process model was created for every intermediate stage of the transformation. Changes were easily integrated in existing PASS models without requiring to completely redraw them. This also made it easier to compare different versions of the same process diagrams and understand what has changed from one version to the next.

The previously mentioned Visio plug-in provided sufficient support for effectuating the required changes to the PASS models. Sophisticated version management features were not needed[5]. This basic tool support has contributed to the role of PASS models as persistent yet changeable tools rather than throw-away documents.

### 7.4 IT Integration

PASS models captured the data exchange requirements for all technical interfaces to be developed. The models were directly usable by internal and external IT experts in all three projects, forming the core part of specification documents for IT interfaces. In Project 3, some of the process models created were sufficiently detailed that the To-Be processes served as test scenarios for acceptance testing regarding the requirement specification.

## 8 Conclusion

*"The tool of the engineer is the diagram"* is an old saying in engineering design, referring to the central importance of using graphical representations for the analysis and synthesis of technical systems. An assumption in business process management is that graphical process models have a similar role in the design and digitalisation of a company's operations. Different notations for process modelling may support this role to a different extent. This article has examined whether the PASS notation exhibits a number of supportive characteristics for process model-driven digitalisation in the manufacturing industry: ease of modelling, distributed modelling, incremental change, and IT integration.

In three digital transformation projects it was observed that, overall, PASS was able to provide these benefits. The PASS models used in the projects served as a practical tool throughout the entire transformation process rather than only in its final stage.

[5] But could easily be provided by external tools like GIT or any common cloud provider

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