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VISUAL MODELLING OF PILOT PRODUCTION TO SUPPORT DECISION MAKING IN PRODUCTION DEVELOPMENT

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1. Introduction

Industrial production faces a challenge of optimisation in almost every aspect, to live up to the continuous demand of increased capacity. Some of the production process issues that are under continuous focus include dimensional tolerances and surface finish, production quantity, production rate, lead time, and robustness and process [Kalpakjian and Schmid 2006]. However, before this can be achieved, the production processes need to be matured to a point where product quality requirements and production capacity needs can be met. When the product to be produced is based on a new technology, never produced in large quantities before, the first priority is to prove that it can be produced at all.

As a central part in production process development, a pilot production can be used as a prototype for the production process, where the processes can be developed, tested, and refined [Oberle 2013]. To be successful, a pilot production should first and foremost be able to demonstrate that the intended products can be produced to the required quality levels. Here, the focus is on achieving control of individual processes, demonstrating scalability of critical production processes, implications of process parameters on product characteristics, and weaving out critical faults in production processes, to a level where the results can provide a foundation for decisions on investing in a full capacity production facility [Oberle 2013]. Therefore, making the right decisions in the pilot production can be crucial for the success in production process development.

A common way of supporting decisions in production is to capture the production process design with a desired perspective. Production process modelling has been done for decades with flowcharts [Gilbreth and Gilbreth 1921], and a large number of different other tools, and most tools are found to be aimed for communicating specifics about the process for further analysis. Most process modelling approaches are aimed to support industrial production and thus highly standardized. Visual modelling approaches have previously been shown to support decision making in production process development projects [Alabastro et al. 1995] and product development projects [Mortensen et al. 2008]. This paper presents the practical experiences from supporting and communicating the decision making for a pilot production setup in a technology development project by visual modelling. The modelling is based on the generic production flow [Mortensen et al. 2011], but in a setting where neither product nor production is yet defined. These results are part of research into the application of visual modelling tools to support decision making in production process development.

The paper is structured as follows: Section 2 highlights and discusses production process modelling methods found in literature and industry. Section 3 presents a case, in which production of a new technology is being developed in order to demonstrate that production of a new Electro-Active-Polymer (EAP) film technology can be scaled, while increasing production quality and EAP film performance. Section 4 presents findings in the case. Section 5 discusses the findings and presents future work. Section 6 presents the conclusion of the paper.

2. Production modelling approaches

This section will review some production modelling approaches found in literature and industry today and discuss their application. The focus will be on diagrammatic modelling approaches [Vergidis et al. 2008].

Flow charts are one of the simplest ways to graphically model production processes [Meyer et al. 2006]. In their most basic form, they comprise no graphical elements other than standardized flowchart symbols, which give no detailed information on the processes that they depict. Within the processing industry, process flow diagrams include standardized abstract graphical symbols to denote important processes and equipment [Silla 2003]. Although they provide more graphical information to the reader, a full understanding of the production process depicted cannot be achieved without knowledge of the symbols, and the processes represented by them. This reduces their effectiveness when they are used to communicate the production process to persons unfamiliar with the symbolism or that lack specialist knowledge of the processes.

The Integration Definition (IDEF) suite and the Unified Modeling Language (UML) have been demonstrated for modelling of production process design [Perera and Liyanage 2000], [Zhang et al. 2007]. Where IDEF has been developed and applied over a number of decades [Spur et al. 1996], the UML is a more recent approach. Both make use of a number of different diagram types to model distinct aspects of a system, but only with standard, graphically simple, notations defined for each modelling approach. Their application to modelling production systems in detail has been shown, from different perspectives, and they are often used in conjunction with process simulation tasks [Oscarsson and Moris 2002].

The generic production flow is a visual modelling approach that has been used in the development of product platforms and families [Mortensen et al. 2011]. The generic production flow visualises the production flow for product variants, through visual modelling of process steps and the resulting output, as well as identifies common process steps. One of the experiences from the application of the model, together with product and market architectures, was reported to be "Improved synchronization between product- and production development." [Mortensen et al. 2011, p. 1] The utilisation of the generic production flow has proved beneficial in the context of product families, but the flow model has not been investigated for use in a pilot production setup.

For the application of most modelling principles, a number of general considerations have to be made. The level of detail to be captured in the model should be defined. The purpose of the modelling should be defined, so the model covers the needs from the users of the model. Considerations about what points in time that should be captured are beneficial. Some projects may have interest in defining the current situation, where others may gain from modelling desired, future setups [Browning 2010].

Visual modelling using graphical elements, icons, to depict process equipment, as part of a simulation model development, has been shown to benefit understanding across knowledge domains and increase commitment from stakeholders [Alabastro et al. 1995].

The generic production flow has been used successfully within product-family development and includes a focus on product variant creation. In the pilot production development of focus in this paper, the ability to produce product variants, and the determination of product characteristics in the production process, is of a high priority. The generic production flow is therefore a solid foundation to build upon for this purpose.

3. Case: visual modelling of the EAP film production

The production of a new technology is being developed by Danfoss PolyPower in order to demonstrate that production of a new Electro-Active-Polymer (EAP) film technology can be scaled, while increasing production quality and EAP film performance [Kiil 2009]. The production of the EAP film has through the past ten years gone from lab production setups to a pilot production setup with the goal of reaching a matured EAP production setup capable of mass-producing the EAP film.

Danfoss PolyPower has, together with a consortium of companies and universities in Denmark, defined a five year, 12 million € project supported by the Danish National Advanced Technology Foundation (DNATF), to mature the EAP technology. The project includes multiple work packages working in parallel to develop materials, production processes, products, mathematical modelling, and prototypes for applications of EAP future products. The modelling task described in this case was initiated by the project manager, accommodating wishes from the case project steering committee, to support the management of the tasks involved with production process development in the project, and the implications on the production. The decision was to model the pilot production setup, with the intended developments in the DNATF project, to support the communication between collaborators and decision-making in production process development tasks.

3.1 Method

The development of the model was carried out in three draft phases, with the drafts reviewed through workshops; the final draft was presented at a project symposium. Figure 1 shows the process followed in the case study and highlights major phases in the development of the model: draft work on the model, workshops for discussion and verification, and feedback. To create a frame for gathering the required data needed for the modelling, with a verified content, data triangulation was used [Yin 2009]. Different sources of evidence were used for data triangulation: documents (previous production process diagrams), interviews (with production manager and production team), and participant observation (as active contributors in the workshops). Workshops were used to involve the production team in the development of the model and to make the progression visible.

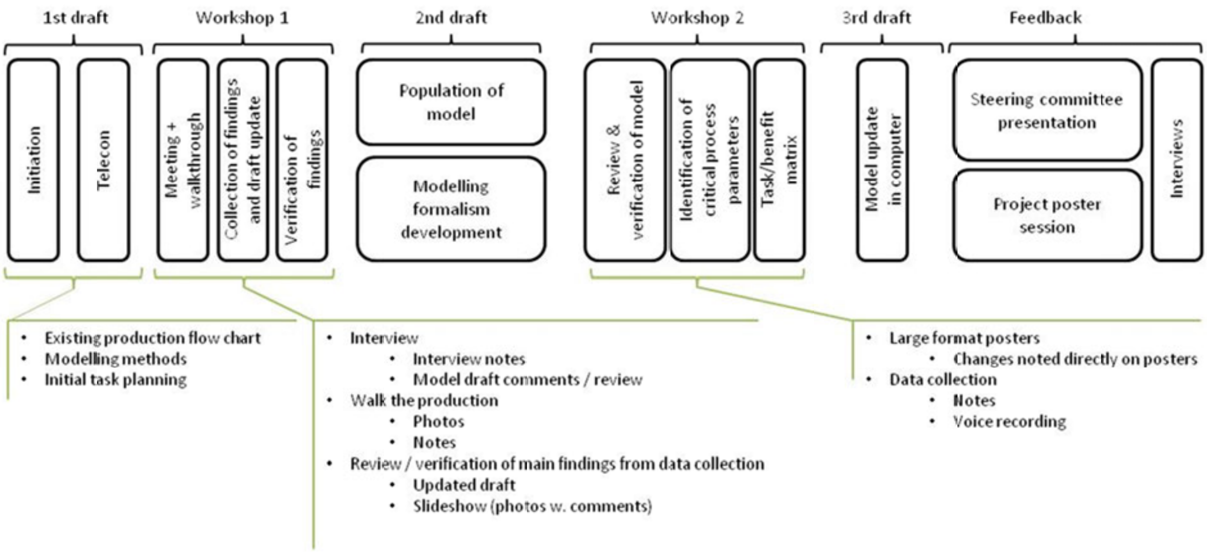

Figure 1. The process followed in the case project, to develop the model

3.1.1 Draft iterations

The initial draft phase involved analysis of existing product process diagram, modelling methods in literature, alignment of expectations between researchers and production manager, and task planning. Subsequent draft phases comprised the main efforts in developing the modelling formalism and modelling elements, which were developed in parallel with population of the model and illustration activities.

3.1.2 Workshop 1

The aim of workshop 1 was to gain a detailed understanding of the production processes to be modelled. This workshop involved data collection activities. An interview was held with the production manager, where a draft model of the production formed a basis for discussions and was commented on by the production manager and researchers. During a walkthrough of the production with the production manager, photos and notes provided the main data collection method. Photo management software was used to produce a slideshow of the photos from the walkthrough with comments by the researchers on the processes depicted by the photos. The slideshow was used, along with an updated version of the draft model, to verify the findings during a review with the production manager.

Figure 2. A large-format poster was used during workshops to facilitate active discussions and enable 'on-the-fly' changes to the model

3.1.3 Workshop 2

Workshop 2 involved, on behalf of the case company, the production manager, the project manager, and two process engineers. At the workshop four posters were utilized, one large format version of each production process to be modelled (past, current, future), and a production overview poster that included all modelling elements (see Section 3.2.1). The overview model was reviewed with the participants, during which comments and questions for discussion were welcomed and, if possible, noted directly onto the poster (Figure 2). Each of the process steps in the production was reviewed in detail to collect information on critical parameters for processes, accuracy of the model, and detail level. The workshop was concluded by reviewing a task-benefit matrix, showing how process improvement tasks within the project were linked to benefits in production performance or quality, and an update of the roadmap for production tasks.

3.1.4 Feedback

The production overview poster was presented by the production team to two recipient groups; the steering committee of the case project during a review and participants from other parts of the case project consortium. Feedback after the case was collected from the production manager and the project manager through interviews.

3.2 The developed model

The production overview, shown in Figure 3, was used to communicate the primary issues of the production development within the case project. The aim of the modelling task was to highlight the intended benefits of production equipment developments and investments, communicate the decisions to be made during the development of the pilot production, communicate the resulting output of key processes, identify where product characteristics are realized in the production process, and communicate the production process design to multiple recipients at different levels in the organization.

The main modeling was done in Microsoft® Visio®, as it was used for the previous flow modeling of pilot production in the company.

3.2.1 General overview

The production overview developed comprises four main sections.

Vision - A graph illustrating the vision of the increase in capacity communicates the aim of demonstrating production scalability. This is linked to (1) the material development progress and (2) the knowledge, and experience, regarding control over the production setup and processes.
Production process - Three production process models of the production, in initial (previous, 2011), present (current, 2013) and projected (future, 2015), respectively. Each production process model instance, in Figure 3 (2011, 2013, and 2015) shows a model of the production process at the respective time in the project. The details of the production process models are elaborated in section 3.2.2.
Roadmap - A roadmap shows the production process development tasks on a timeline, to illustrate the completed, current and ongoing tasks. The roadmap showed parallel development tasks aimed at improvements in all process steps.
Benefit of improvements - A task-benefit matrix shows what benefits or capabilities that completed production process development tasks will enable, in a number of dimensions, e.g. performance or product quality. The matrix showed that some benefits were realized by not only one task, but multiple tasks. Many of the tasks were also linked to multiple expected benefits.

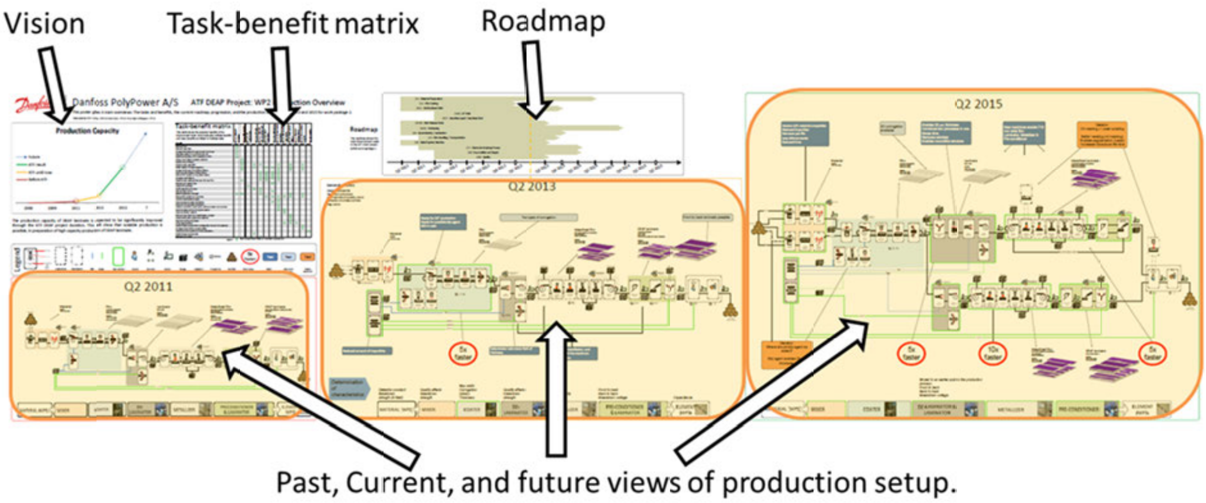

Figure 3. Production overview poster from case project

3.2.2 The production process models

The production process models share the same modelling formalism. Figure 4 shows part of the production process model for 2013, along with selected modelling elements used in the modelling formalism to denote important issues. The production process models communicate the following aspects:
The process flow - Each of the process steps are illustrated by a rounded rectangle with a principle illustration to show the function of the process to aid communication to a wider audience. In addition, critical process parameters are noted for each process. The border of the rounded rectangle is used to indicate those cases where the process is implemented but not used or where a decision needs to be made for the particular process. The main difference, as opposed to the generic production flow model, is the focus on the processes and their critical parameters, their change over time, and their ability to create output variants, instead of identifying variant creation points within a defined product family.
Storage and transport - Storage and transport means between stations is illustrated, by graphical icons, to enable future analysis and optimizations of the production setup e.g. in relation to production scale-up.
Main stations - The main stations (machines) utilized in the film production are noted at the bottom of each model and as shaded backgrounds in the production process model. The colour of the shading links the two representations. The border of the rounded rectangle is used to indicate, those cases where the process is new.

Resulting output - The resulting output of each main station, in terms of film variants, is illustrated by CAD illustrations, highlighting where in the processes the variants are defined in the production.
Process time - Two types of information on processing time are communicated in the models. The processing time for a single batch of a certain size, is noted for each main workstation. An estimation of how many times faster a process will become with a planned upgrade from the roadmap is noted by a red circle for each workstation improved, for the particular production process model instance.
Critical decisions - Decisions to be made on workstations or processes are noted on the production process model. For each critical decision, the known alternatives and implications are noted concisely.
Achieved characteristics – At the bottom of each production setup view, the main stations of the production are modelled, with film characteristics noted. This links the achieved film characteristics to the main process steps, indicating where changes should occur in production to affect film characteristics.

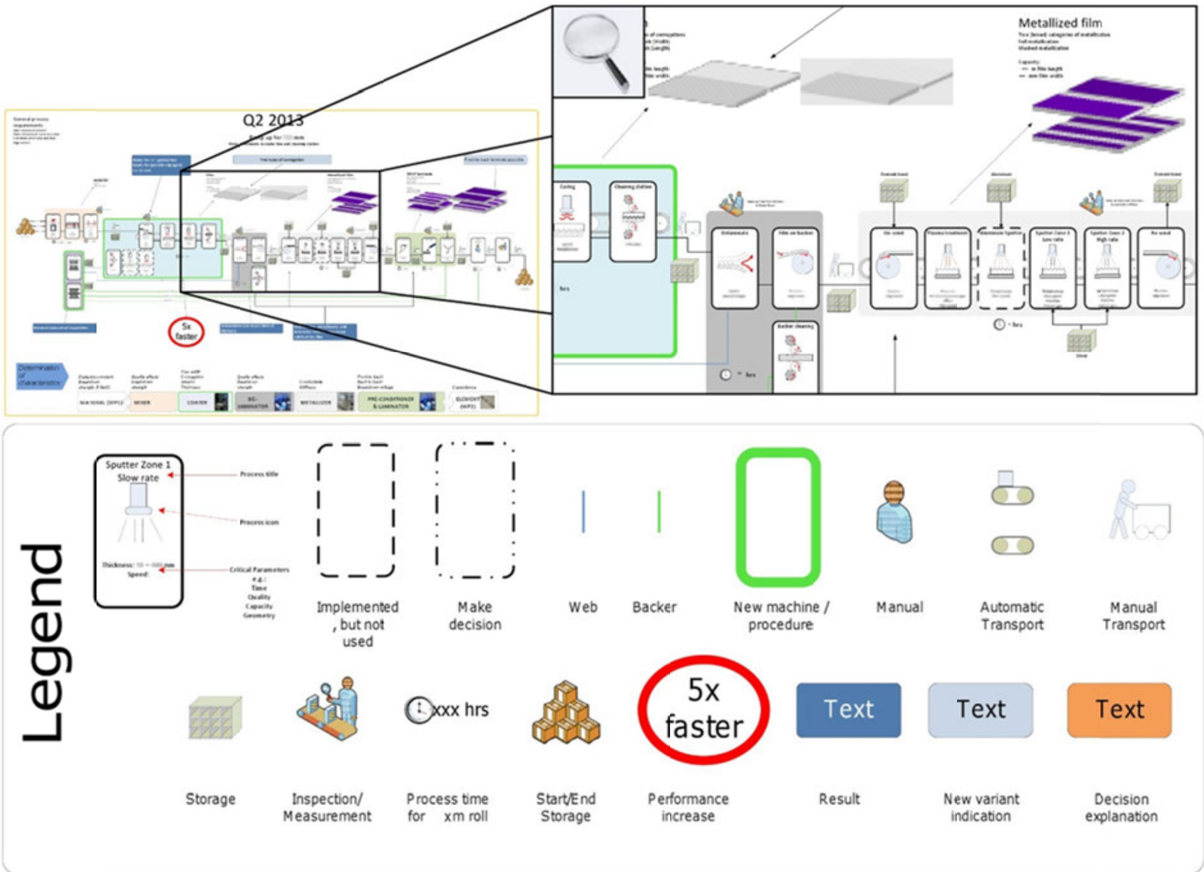

Figure 4. Part of the production model of current production (top). Legend of the modelling formalism (bottom)

4. Findings

The findings reported here stem mainly from the workshops, as observations, and from feedback interviews with the project manager and the production manager. Findings on the modelling process, as well as the use of the model for internal and external communication by the production team are treated in this section.

4.1 The modelling process

Using a commented slideshow presentation of photos to verify findings during workshop 1 was found to be a strong tool to create discussions and highlight the overall flow, and details, in a visual manner.

This reduced the amount of misconceptions after the first workshop, thus reducing the resources required to reach an accurate model of the production.
Bringing large-format print-outs, A0 or larger, of the model to workshops was found to be a crucial aspect in discussing the contents of the model, as well as noting comments, changes and suggestions 'on-the-fly'. The large format allowed the whole team to see details on the model and contribute to the session (see Figure 2). Bringing the production team together to discuss the models had a positive effect on bringing up issues regarding the production process development. The production team initiated discussions during workshop 2 to reflect on implications of new machinery, improvements of processes, and identification of critical process parameters.
The task-benefit matrix captured many of the links between intended benefits from the project and the production process development tasks in the project. The critical process parameters could be noted directly on the production process models, as well as implications of decisions on processing equipment or process flows.
Visualising the production process steps for the production team enabled them to 'show' the core of the process and how it is linked to the characteristics of the products; knowledge that was previously only found within the minds of the production team members. This link between the characteristics of production and production output (in this case the DEAP film) allowed the team to reason about future updates and predict what effect changes would have on the film. At the end of workshop 2 it was discussed by the team, whether it should be used for presentation of the production setup to an external vendor, as they saw it as a tool to provide the external vendor with a greater understanding of their production process.

4.2 Communication within the production team

The overview brought by the model, and the level of details in it, ensures that the production team is aware that they also need to keep 'this and that' in mind, when considering the production process. In interviews it was stated, that the visualisation, as opposed to standardized flow charts, made it easier to 'see' how a change in one process would affect further down the process flow. The model is therefore used whenever pros and cons of suggested process changes are discussed within the production team. The model effectively communicates what the activity is, what the process is, and what is critical. The link to what output variants are realized and what product characteristics are determined, by the process, shows what the purpose of the production process is.
The task-benefit matrix was intended to highlight what the different tasks/improvements would help on in the production, but when interviewed for feedback, the production manager stated that the team used the flow-models for discussions on improvements and the project manager stated that the full potential of the matrix was yet to be realised.

4.3 Communication outside the production team

The modelling task was considered to have fulfilled the goals of the steering committee, which initiated the task.
The model has been used to communicate the production process to parties outside the production team, both within the business unit and collaborators in the DNATF consortium. The production team has experienced the use of the model as beneficial for their ability to explain the process to external parties. Here, the graphical elements play a large role, according to the project manager, in explaining the production process to stakeholders that are not deeply involved with the production process. This was also viewed as an indicator that the model was a success by the project manager. That the production team could use the model, and explain it; especially that they could use it to explain to others what the production process, and its development, is all about.
The production manager has the intention of keeping the models updated for further use, as the production process models eased communication of the production process to parties both inside and outside of the production team.
For communication to persons outside the business unit, it was stated, that the overview may contain too detailed information, but for discussion within the production team the overview had a fitting level

of detail. It was, however, also noted by the production manager that it is easier to reduce the detail level for another recipient, than it is to increase the detail level.

5. Discussion and future work

There may be limitations to implementing the presented model in industry. The modelling formalism does not adhere directly to current practices in production models, frequently used by production managers and often integrated into PLM systems. Therefore, multiple models might need to be kept up to date in some companies, if this modelling was adopted. The present model, although based on models and approaches previously tested in industry, has only been implemented in an early stage production development, with a new product and new production. Its application within a more mature industrial setting has not been investigated.

In the EAP case, it was found through the interviews that the visual model presented the production team with a high amount of detail. This was reported to be of little matter, as the visual approach helped the team in the current phase of defining the production process. At a later stage, the model can be used as a base for a standardised flow chart, when the main process setup is in place, should a standard flow chart be preferred at that stage. The level of detail in the model was a result of the data collection and the extended generic production flow model formalism. As to the aim of having a model that allowed for communication with multiple recipients at different levels, the model has introduced an increase in detail when compared to the existing flow chart in the case. The aspect of communication internally in the production team and with externals revealed two different dimensions to be taken into account, an overview request driven by manager level, and detail request, driven by the expert team. This matter might be resolved in some cases by introducing layers, defined in the software, which allows details to be hidden for some recipients while using the same document. It is, however, an aspect that should be considered carefully, as adding layers may add detail as well as create confusion when deciding to what layers new changes shall apply. It is important to underline the fact that the main observations on the use of the model was made on printed versions of the model, not the virtual model. Further research on the use of the model in regards to updates, changes etc. would need to be investigated to evaluate the daily use of the model. As the developed model does not follow standard practises within companies to model production processes, finding employees that are comfortable with keeping the model updated may be an issue. However, the software used is readily available, relatively well known in industry, and often used for flow models in industry.

The model presented in this paper is not intended to work as a total definition of the production setup – it is intended to provide an overview of key factors to support discussions and decision-making, and its fitness to other purposes depends on its alignment with those purposes [Browning 2010]. The visual model has its strength in providing overview, details, and means for communication, in a technology pilot production. The applicability of this modelling formalism within established industrial production has not been investigated in this case.

The EAP film production is only a part of the production of an EAP transducer. Harlou [2006] emphasises the alignment between market, product and production architectures, as adapted in Figure 5. Within the DNATF project, the definition of transducer types is ongoing, supported by the Conceptual Product Platform (CPP) [Guðlaugsson et al. 2013], which looks into the market and product family views, and a system architecture modelling approach for support of the integration in test applications of the EAP, as illustrated in Figure 5. The work done with the CPP feeds into the definition of EAP transducer type definition. To support the transducer production, the proposed modelling approach can be further expanded, to support design decisions for the production of EAP transducers with links to the EAP transducer architecture from the CPP.

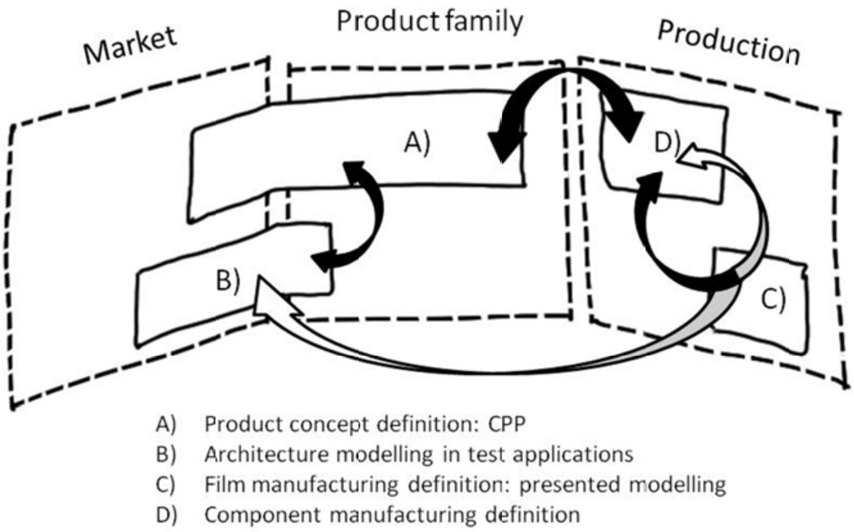

Figure 5. Linking market definition, concept definition and production definition. Black arrows represent content links and light arrows represent modelling formalism links. Market, product family, and production views adapted from Harlou [2006]

6. Conclusion

A visual production model, based on the generic production flow has been developed for a pilot production in a technology development project of EAP film. The model has been well received by the production team and is being used both for internal communication and communication outside the team to illustrate the decisions, future changes, and the links to both an upcoming EAP component platform as well as the visual modelling of systems with which the EAP is being integrated. The visual model supported the management of tasks involved with production process development in the project, by fulfilling the following aims:

- Identify benefits of production equipment developments
- Communicate decisions during development of pilot production
- Communicate the resulting output after key processes
- Identify where in the production process, product characteristics are realised.
- Communicate the production process design to multiple recipients at different levels.

The method has given suggestions to the process of documenting the production in an early setup and the findings from the case project indicate that workshops on documenting the production process can help make the tacit knowledge of stakeholders explicit. The follow-up feedback stated, that the modelling was a help in the daily work in the production team.

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References

Alabastro, M. S., Beckmann, G., Gifford, G., Massey, A. P., Wallace, W.A., "The Use of Visual Modeling In Designing a Manufacturing Process for Advanced Composite Structures", IEEE transactions on engineering management, Vol. 42, No. 3, 1995, pp. 233-242.

Browning, T. R., "On the alignment of the purposes and views of process models in project management", Journal of Operations Management 28, 2010, pp. 316-332.

Gilbreth, F. B., Gilbreth, L. M., "Process charts", American Society of Mechanical Engineers, New York, 1921.

Gudlaugsson, T. V., Mortensen, N. H., Sarban, R., "EAP high-level product architecture", Proc. SPIE 8687, Electroactive Polymer Actuators and Devices (EAPAD) 2013, Yoseph Bar-Cohen, San Diego, California, USA, 2013, pp. 868710-1 - 868710-8.

Harlou, U., "Developing product families based on architectures", PhD thesis, Technical University of Denmark, 2006.

Kalpakjian, E., Schmid, S. R., "Manufacturing engineering and technology", Pearson Education, Upper Saddle River, New Jersey, USA, 2006.

Kiil, H.-E., Benslimane, M., "Scalable Industrial Manufacturing of DEAP", Proc. SPIE 7287, Electroactive Polymer Actuators and Devices (EAPAD) 2009, Yoseph Bar-Cohen, Thomas Wallmersperger, San Diego, California, USA, 2009, pp. 72870R-1 - 72870R-10.

Meyer, U. S., Creux, S. E., Weber Marin, A. K., "Process Oriented Analysis", CRC Press, Boca Raton, Fl, USA, 2006, pp. 37–95.

Mortensen, N. H., Hansen, C. L., Hvam, L., Andreasen, M. M., "Proactive modelling of market, product and production architectures", Proceedings of the 18th international conference on engineering design: impacting society through engineering design, Vol. 4, Kgs. Lyngby, Denmark, 2011, pp 133-144.

Mortensen, N. H., Pedersen, R., Nielsen, O. F., Harlou, U., Bøgh, M. H., Høgh, P. T., Hvam, L., "Implementing a product platform in 35 man-days: the visual thinking approach", International Journal of Mass Customisation, Vol. 2, No. 3, 2008, pp. 240-263.

Oberle, T., "Process techniques for engineering high-performance materials", CRC Press, Boca Raton, Fl, USA, 2013, pp. 235–272.

Oscarsson, J., Moris, M. U., "Documentation of discrete event simulation models for manufacturing system life cycle simulation", Proceedings of the 2002 Winter Simulation Conference,Vol. 2, Yucesan, E., Chen, C.H., Snowdon, J. L., Charnes, J. M., eds., San Diego, California, USA, 2002, pp. 1073-1078.

Perera, T., Liyanage, K., "Methodology for rapid identification and collection of input data in the simulation of manufacturing systems", Simulation Practice and Theory 7, 2000, pp. 645-656.

Russel, R., Taylor, B., "Operations Management", 7th edition, International Student Version, John Wiley & Sons, Inc., Hoboken, New Jersey, USA, 2011.

Silla, H., "Chemical Process Engineering: Design and Economics", Marcel Dekker, Inc., New York, NY, USA, 2003, pp. 1–28.

Spur, G., Mertins, K., Jochem, R., "Integrated Enterprise Modelling", Beuth Verlag GmbH, Berlin, DE, 1996.

Vergidis, K., Tiwari, A., Majeed, B., "Business Process Analysis and Optimization: Beyond Reengineering", IEEE Transactions on Systems, Man, and Cybernetics - Part C: Applications and Reviews, Vol. 38, No. 1, 2008, pp. 69-82.

Yin, R. K., "Case Study Research", Sage Publications, Thousand Oaks, California, USA, 2009.

Zhang, L., Jiao, J., Helo, P. T., "Process platform representation based on Unified Modelling Language", International Journal of Production Reseach, Vol. 45, No. 2, 2007, pp. 323-350.

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