Media-Assisted Product and Process Requirements Traceability in Supply Chains

Matthias Jarke, Oliver Fritzen, Michalis Miatidis, Marcus Schlüter
Informatik V, RWTH Aachen, Ahornstr. 55, 52074 Aachen, Germany
jarke@cs.rwth-aachen.de

Requirements engineering for technical systems involves an intricate interplay of conceptual synthesis of alternative requirements and design configurations, preliminary impact analysis of these alternatives using complex simulations and multimedia visualizations, and human decision-making based on goal trade-offs. Requirements traceability in such settings must be both product- and process-oriented: it must enable an efficient media-based comparison of product alternatives from the current project or related experiences, and it must facilitate reuse of analysis process experiences to avoid unnecessary repetition of negative experiences. We study these problems in a large interdisciplinary project whose aim it is to optimize the innovation supply chains linking chemical engineering, plastics engineering, and application goals e.g. in the automotive industry.

1. The Plastics Engineering Supply Chain

Plastics parts, such as cooler fans or airbags in cars, are often based on the chemical product family Nylon 6 because of its excellent mechanical and thermal properties. As figure 1 shows, the requirements definition involves a cooperation of chemical engineers, plastics engineers, and mechanical engineers. Both the *synthesis* and the *separation* of Nylon 6 are designed by chemical engineers, while the properties of the final moulded parts constitute the *goals* of the RE process. For example, in a car the cooling fan and the induction pipe near the engine have to be resistant against oil, fuel and heat; the fan also requires mechanical stability for the high rotation speed.

Compounding is particularly interesting for supply chain RE because it sits in the middle between continuous chemical production processes, and discrete mechanical configuration of end products. Compounding employs closely intermeshing, co-rotating twin screw extruders built up from discrete modules on which controlled physical and chemical processes assist in mixing fillers, reinforcing fibres, and additives into the raw material, to produce different construction materials. Extruder size and screw geometry must be designed with great precision to realise the desired material modifications in an effective, economical way. Each engineering discipline employs its own mathematical models and software tools for requirements validation and impact assessment, until recently only linked by standard product catalogues. Global design optimization of the interplay of RE decisions in the supply chain is a major goal of Aachen's DFG-funded Research Center on Cooperative Computer-Aided Process Engineering (SFB 476 IMPROVE).

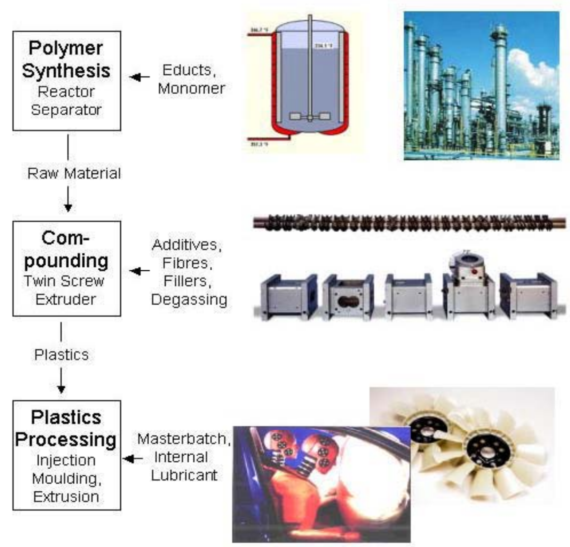

Fig. 1: The Plastics Engineering Supply Chain

2. RE Process for Plastics Engineering

The basic shared artefact for interdisciplinary understanding are hierarchically organised flowsheets. Such flowsheets usually come in three flavours: An abstract initial process flowsheet is mapped to a functional zones representation which is still shared across engineering disciplines. In contrast, device-level flowsheets refer to individual engineering specialities, specific device types and process control systems.

Evaluating the mapping from functional zones to their detailed physical implementations is very costly and thus a prime candidate for experience reuse. It involves an iterative, interdisciplinary, and reuse-oriented interplay :

- select extruder size referring to machine data sheets;

Proceedings of the 11th IEEE International Requirements Engineering Conference
1090-705X/03 $17.00 © 2003 **IEEE**

- design basic screw configuration using experience;
- analyse screw geometry with 1D simulation software for integral process properties like pressure, temperature or shear rate of the polymer.
- analyse specific functional sections by 3D-simulation to study special effects like residence time, deformation or mixing [HS01].

Standardized exchange of heterogeneous requirements information, shared understanding across disciplines by visualization, traceability of interdisciplinary design decisions, and corresponding reuse of experiences both from the product and the process perspective are crucial for both quality and cost-effectiveness.

Our solution to these problems is an adaptation and extension of the PRIME Process-Integrated Modeling Environment [PW+99]. PRIME builds on a decision-oriented and situation-based process meta model. A detailed trace is maintained of how engineers step through the various contexts. Tools can be process-integrated by tool process models. Process fragments, product objects schemas, and traces that instantiate these metadata are maintained in a Process Data Warehouse PDW [JLK00]. Metadata are formalized in modular Telos [NJ99], while trace instances are kept in an XML database, organized according to the MPEG-7 standard to handle the different media (model data, visualizations) of trace information.

The PRIME machinery was used to develop a novel process-integrated *flowsheet editor* based VISIO. In addition to process guidance and trace capture across tools, process integration also allows externally defined tool extensions such as supporting the full hierarchy of flowsheet refinement inline. A domain-specific reuse tool called *FZexplorer* was process-integrated with flowsheet editor and 1D simulator to facilitate efficient reuse of mapping experiences for given functional zones.

Analysts use 3D simulation if subtle design decisions involve highly time- and space-dependent effects. Only the visualization of such simulations enables the experienced plastics engineer to evaluate a proposed alternative with respect to the goals and obstacles relevant to the next stage in the supply chain. However, it usually requires many simulations to find a satisfactory solution. Comparing all the visualizations with respect to multiple goals can take a long time. The problem increases when reuse across projects is enabled. Simple linkage of such multimedia scenarios to goals [HPW99] turned out to be insufficient.

Piggybacking on the well-known phenomenon of 'zapping' across TV channels, we have developed the TRAMP tool (fig. 2) which offers 'semantic zapping' as a kind of media-based product family analysis complementing more formal techniques such as [WW03]. Building on the MPEG-7 metadata of the PDW, the three columns of buttons on the right of fig. 2 reflect the metadata categories of goals, materials and device type ontologies. Selection fills the thumbnail gallery with visualizations of 1D and 3D simulation results relevant to the indicated combination of goals, materials, and device types. Dragging one of these thumbnails into the center enlarges and plays the corresponding multimedia object, thus enabling human judgment. Particularly promising or bad alternatives can be drawn into the personal collection at the bottom left and annotated with arguments linking them to the Decision Editor of the PRIME environment.

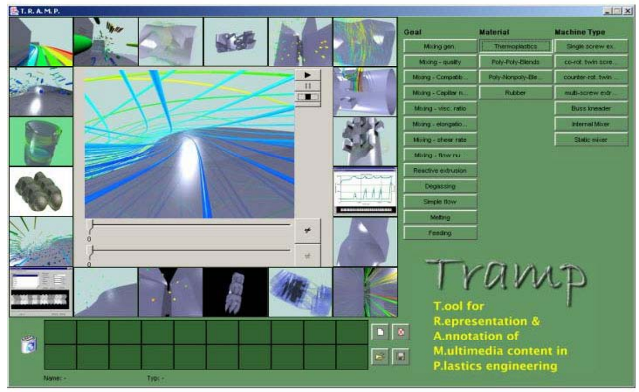

Fig. 2: TRAMP screenshot showing RE product reuse

The efficiency gain in supporting media-based analysis of multiple alternatives with subtly different degrees of goal achievement has been substantial in early experiments with plastics engineers. Together with the process integration which largely automates the capture of traces, a major step towards the reuse of experiences in this complex interdisciplinary and compute-intensive setting seems to have been accomplished.

References

[HPW98] Haumer P., Pohl, K., Weidenhaupt, K. Requirements elicitation and validation with real-world scenes, IEEE Trans. Software Eng. 24, 12 (1998), 1036-1054.

[HS02] Haberstroh, E., Schlüter, M.: Design of twin screw extruders with the MOREX simulation software, Proceedings PPS 18, Polymer Processing Society, Guimaraes, Portugal, 2002

[JLK00] Jarke, M., List, T., Köller, J. The challenge of process data warehousing, Proc. 26th VLDB Conf., Cairo 2000, 473-483

[NJ99] Nissen, H., Jarke, M. Repository support for multi-perspective requirements eng., Inf. Sys. 24, 2(1999), 131-158

[PWD+99] Pohl, K., Weidenhaupt, K., Dömges, R., Haumer, P., Jarke, M., Klamma, R. Process-integrated modelling environment (PRIME): foundations and implementation framework, ACM TOSEM 8, 4 (1999), 343-410.

[WW03] Weber, M., Weisbrod, M. Requirements engineering in automotive development: experiences and challenges, IEEE Software 20, 1 (2003), 16-24.