INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

SUPPORTING DECISION MAKING WITH AGENT BASED MODELLING AND SIMULATION

H. Nergård, C. Johansson and T. Larsson

Keywords: decision making, product development, agent-based modelling and simulation

1. Introduction

In aeronautics today, manufacturers make extensive use of modelling and simulation capabilities with the purpose to design and evaluate specific engineering tasks and related parameters. The objective with these activities is to further reduce cost, lead-time and increase quality to strive for greater competitiveness, market share and sustainability. In recent years, aeronautics have shown interest in the concept of providing a Total Offer (TO) or selling a Functional Product (FP) [Alonso-Rasgado et al, 2004] (a.k.a. Product Service System (PSS) [Matzen et al, 2005]). The functional product, consisting of both hardware and service components developed simultaneously, provided as a function to the customers, calls for a different approach in the development process, i.e. a Functional Product Development (FPD) process [Nergård et al, 2006]. The main reason for this is the perspective of the product's life cycle. Instead of components being sold to and owned by the customer, the hardware and service provided as FP implies that ownership and thus the risk remains with the manufacturer throughout the life cycle of the provided function.

In order to reduce the risk, and make use of the possibilities for continuous product development and remanufacturing, companies are moving towards making more use of modelling and simulation capabilities not only for the design but *also* in order to decide whether to offer the product as a FP or as a traditional hardware product.

Modelling and simulation methods such as Computer Aided Design (CAD), Finite Element Analysis (FEA), multi-body dynamics (MBS) and Computational Fluid Dynamics (CFD) are relatively mature and extensively used in most product development projects in aeronautics as design and development support tools. As these methods are maturing, they are integrated in support tools for engineers, such as Knowledge Based Engineering (KBE) applications to a larger extent. However, these support tools are still used for the design and verification of specific engineering activities. This perspective supports design on a micro (individual activities) level, while on a macro level, with a holistic perspective of the product development process (PDP), the individual PD-activates can be seen as building blocks of the total system. Although it is possible to use these Knowledge Engineering (KE) applications to model the overall macro-level PD-process there are some issues that makes them less suitable. The level of detail in KE applications is not interesting in a macro-level model where the behaviour and interaction between applications, people, and resources are more interesting. The time each iteration takes has also to be considered, due to the fact that a model that takes hours to simulate is not suitable for use in a macro-level model where the simulation is run over longer model time intervals. Agent-based modelling [Sichman et al, 1998] is an approach where agents (i.e. micro level activities) are utilised to build a system (i.e. process) bottom-up by modelling the behaviour and interaction of the agents in a certain environment. This approach seems to be suitable from a macro level perspective, as information about PD-activities can be included in the agent's behaviour. The objective of this paper is to discuss agent based modelling and simulation as decision support in functional product development, and to show example of the approach.

2. Method

The ideas that are presented in this paper are based on experience from participation in a number of workshops regarding computer support tools for decision-making and also regarding knowledge maturity. The workshop on computer support for decision-making was performed in collaboration with participants from academia and a company in the aeronautics industry in Sweden. The workshop was held in a future-workshop format. The workshops on knowledge maturity were performed in an action-oriented manner, where participants from the same industrial organisation as above elaborated on a plausible change to the offer development process. Further, the authors have participated to a number of workshops and meetings with a centre for collaboration with industrial partners from the manufacturing industry in Sweden. Here these ideas have been discussed and feedback has lead to further development and applicability of the ideas.

3. Area of Application

Usually, PD-activities are just a series of cost accumulation points, in the sense that no profit is made before a product is sold. However, there are opportunities to govern PD performance to reduce the rate of negative cash flow. The goal is to be as effective as possible and the means to accomplish this is awareness of how the life cycle perspective affects the PD-process.

Buxton et al [Buxton et al, 2006] shows that different business scenarios and aftermarket solutions in the aero engine industry can be modelled with an agent-based modelling and simulation approach. By varying contractual parameters in the agent-based model, such as "usage contracts" (i.e. total offer) versus traditional offers, different curves, representing payback rates, are obtained. An illustration of this may be seen in figure 1.

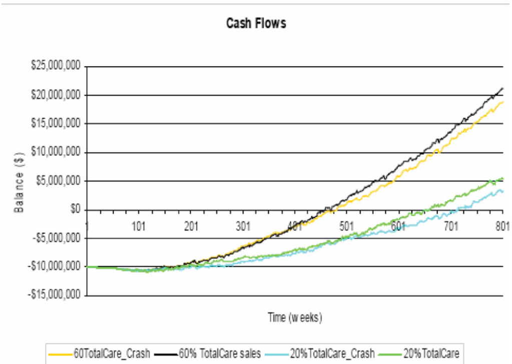

Figure 1. Payback curves, adopted from Buxton et al (2006)

The starting point in figure 1 is at the point of delivery ($x = 0$) of the product. Buxton et al (2006) has examined the use of Agent-based modelling (scenario, contract, value-chain, business models etc). Buxton et al (2006) assumes a static cost rate for the product development phase (on the negative side of the x-axis). This is not representative of the actual product development process, where many parameters influence its behaviour and thus its time and cost. The PD-cost rate is therefore more of the dynamic sort rather than static and is also influenced by different scenarios and business cases, see figure 2. Therefore, modelling and simulating the product development process *as well* promises to examine how the actual PD-process affects both the payback curve and the point of delivery. In the TO scenario this means modelling and simulating both the product development and service development processes, i.e. the FPD-process, and the FP's life cycle.

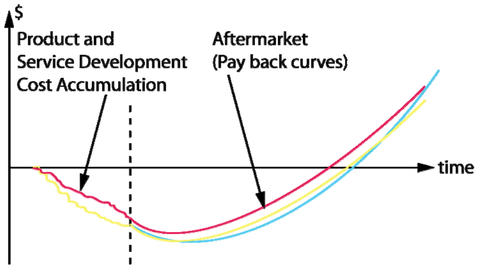

Figure 2. PD-cost rate in relation to Buxton's et al payback curves

The Functional Product's life cycle can, in a simplified and holistic manner, be represented as figure 3. The first step is the proposal development process, where a request for proposal (RFP in figure 3) from a potential customer is processed. If a Go-decision is taken on the proposed business opportunity, the PD and SD phase of the project can commence. As the functional product is completed, it is delivered to the customer.

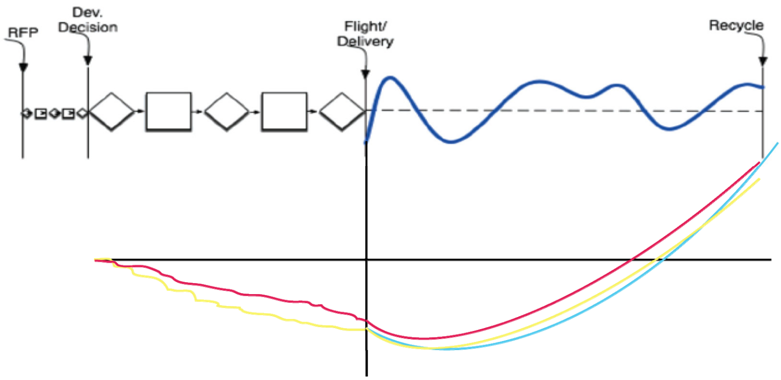

Figure 3. A product life cycle from a holistic perspective with offer development, product development, usage (after market), and R&D processes in parallel

Modelling and simulating the PDP in combination with different business cases and scenarios gives a certain forecast as to what the best or worst case is. Modelling and simulating complex processes and their interaction have been done within the system dynamics discipline, using state-charts and stock-and-flow models, to model complex systems with dynamic behaviour. Another modelling technique used to model dynamic behaviour is Agent-based modelling and simulation (ABMS) [Borsches, 2004]. Agents can be regarded as personas with provided properties, rules and limitations, on which they base their behaviour and interaction with other agents in the environment (i.e. organisation) they exist in. Agent-based models, in contrast to other system dynamics modelling approaches are suitable for bottom-up modelling approaches, i.e. building agents in an iterative approach, beginning with just a few behaviours and then increasing the agent properties as more information is gathered.

4. Total Offer Readiness Level – a Decision Support

When considering offering a product as a TO, the first thing that a manufacturer wants to know and has to decide on is; should the product be offered as a FP? Or, should the manufacturer offer the product as a traditional offer? This is where the concept of Total Offer Readiness Level (TORL) comes in, to be able to assess and decide whether to take a Total Offer responsibility or not. Ericson et al (2007) states a need for a TORL as a support tool for decision makers:

"The total offer calls for integrating a diversity of knowledge areas, e.g., business, design and manufacturing, accordingly affecting the product development process in the same way. Besides

insisting on coordination and communication in a cross-boundary setting, making the right decisions at the right time is vital in this setting.[…] It is not apparent which aspects a tool to aid decisions in early design phases of physical artefacts sold in total offers needs to support." (Ericson et al, 2007, p. 608)

The Readiness Level (RL) part in TORL implies that concepts of maturity (i.e. Knowledge Maturity, Technology Readiness Level (TRL), etc.) are used as decision support, to assess the quality of the knowledge about the Product Development activities. TRL [Mankins, 1996] is a concept developed by NASA and adopted by parts of the aerospace community, where using generic sentences to prescribe development and testing activities needed to mature a technology.
Knowledge maturity [Johansson et al, 2008] is a concept where team members use criterion to assess level of knowledge in decision content and rationale and thus instilling confidence in decisions.
A technology may be very mature and easily applied, i.e. a high TRL. However, the person applying it can have a low level of knowledge about the effects of applying the technology, i.e. low knowledge maturity. These are two components that are important to utilise in the TORL decision support.
To be able to make a model of the proposed TO/FPD-process and the results and effects of its simulation on the FP-life cycle available to decision makers, a visual representation of TO feasibility is needed. Hence, a concept of a Total Offer Readiness Level has been developed as a research teaser in order to gain further input and feedback from industry.
The demonstrator (see figure 4) is developed in Microsoft Excel and shows the steps that are needed in a product development process with four gates that have to be passed in order to realise the total offer. Each activity in the PDP features up to nine levels of readiness that are manually filled in if it is fulfilled or not compared to a pre-decided GO-/NO-GO-level. The GO-/NO-GO-level corresponds to the amount of risk the company decides is suitable at a certain point in time.
This demonstrator show the main idea of TORL decision support, but everything is manually set in real time and does not show the dynamic interaction between PD activities. In order to examine the dynamic behaviour, a more simulation-orient approach is needed. Below, in section 5, follows a discussion of how to represent this in an agent-based model.

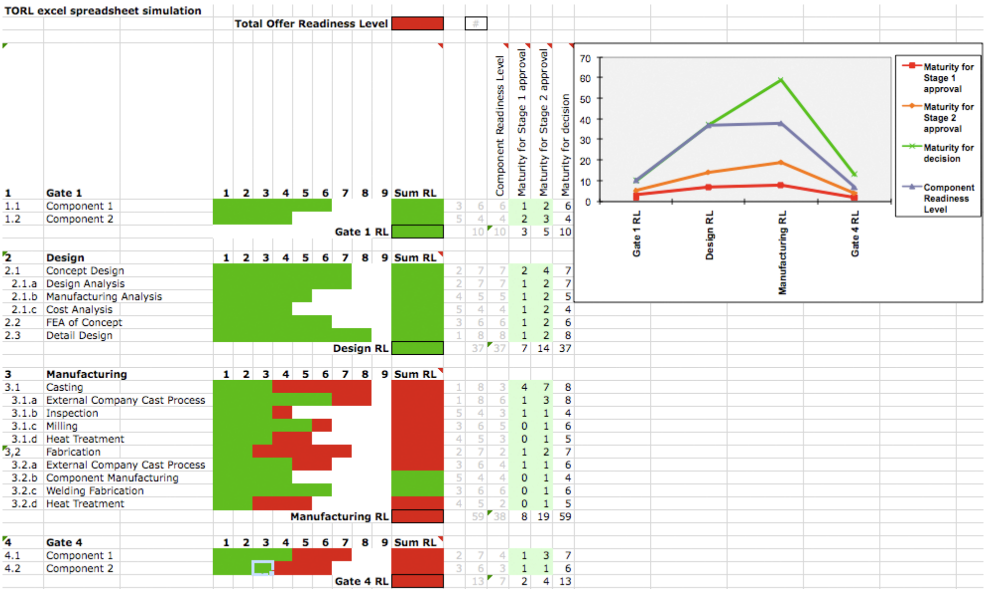

Figure 4. First demonstrator of Total Offer Readiness Level (TORL)

5. Agent-Based Model

As a discussion about the relation between the TORL and Agent based modelling of the PD and SD processes the following example is given: Consider a product development process (the information in the generic process is inspired from previous studies and work) that consist of a number of overall activities as shown in figure 5.

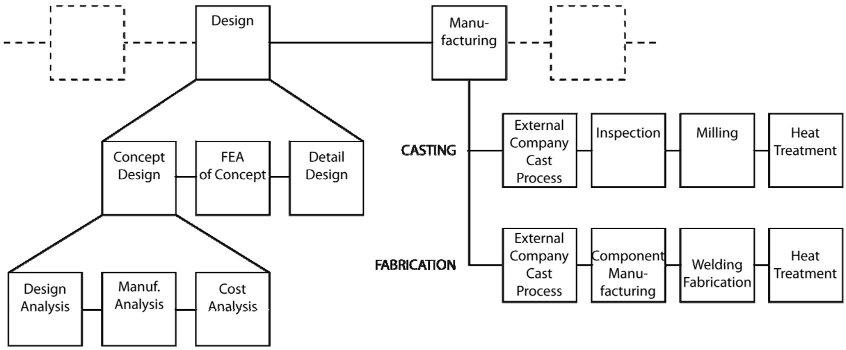

Figure 5. Excerpt of FPD process showing activities for design of an aero engine component.

These are the essential steps that summarises a company's product development process in order to design and manufacture an aero engine component. Breaking down the design activity into smaller more detailed activities of the Concept Design phase you end up with three activates; Design Analysis, Manufacturing Analysis, and Cost Analysis that are necessary to generate a number of concept that later on can be further developed and evaluated. At this early concept design phase the designer decides whether to use one of two different manufacturing processes; casting of the whole design or manufacture a number of parts that are to be fabricated (welded) together into the same geometry.
The details in these analyses can vary from coarse (based on designer experience) to very high detail (advanced KE and CAE-support tools). This corresponds to a micro-level perspective, that is, high-level of detail. Although on a macro-level, using Agent-based modelling some of these details are not suitable. Table 1 shows a comparison of the differences in parameters between the micro-level and the macro-level.

Table 1. Moving from micro-level to macro-level perspective

Micro-level activity	Micro-level parameters	Macro-level parameter	Macro-level activity
Boss Design	Hole width, boss shape, boss height, inside or outside, surrounding geometry, load case, amount of heat, connecting geometry. Analysis output	Time, resources, cost, level Knowledge maturity, level of TRL, information needed, communication needed. Information output. Activities needed	Boss-design agent, FEA agent, Cost agent, Knowledge Maturity agent, Etc.
FEA-analysis	Start geometry, adapted geometry, load cases, flows, heat, etc, number of computers needed, software needed, expertise needed, create analysis model	Time, number of computers needed, Area of application, knowledge and information needed, time for setup, time to model, time for simulation,	FEA agent, Cost Agent, etc.

Agent representations of all these activities do not have to be created. For instance only one Agent have to be created that is specialised in calculating i.e. cost. This agent calculates cost in any place, at any time but depending on the application and activity (i.e. context) it analyses, its cost calculations are adapted. This also corresponds to an Agent that specialises in analysing and representing FEA.

Depending on e.g. geometry and area of applications, the Agent uses different types of FEA-representations of the analysis performed.

In figure 6, an agent-based version of the TORL decision support, of the example PDP (figure 5) is shown. The model has been implemented in the commercial simulation software XJ Technologies AnyLogic 6 (www.xjtek.com). The bottom-left, top-right, and bottom-right quadrant shows the agent-based representation of the process, a FEA agent, and Cost agent respectively. These representations have been modelled as separate agents with individual behaviour. The process agent is modelled to be the governing model that calls upon other agents as needed. The process agent uses a state-chart to replicate the steps in the PDP. The process agent can be changed in the way the user see fit and calling in other agents that are necessary to perform the PD-process. If the amount of Agents is not satisfactory an arbitrary number of Agents can be replicated, which in real life would correspond to changing the amount of resources that is available. It should be noticed that the process agent does not explicitly send messages or information to another specific agent; instead it sends messages to the environment. The agents have been programmed to only accept messages that are of use to them and otherwise they "bounce" the message back to the environment and thus instilling a more autonomous behaviour in the system. When an agent accepts a message it is taken care of by the receiving agent and the overall process is paused in the state that sent the message. The activated agent performs its internal activities and when finished sends a "READY" message back to the process agent that continues with the next step in its state chart.

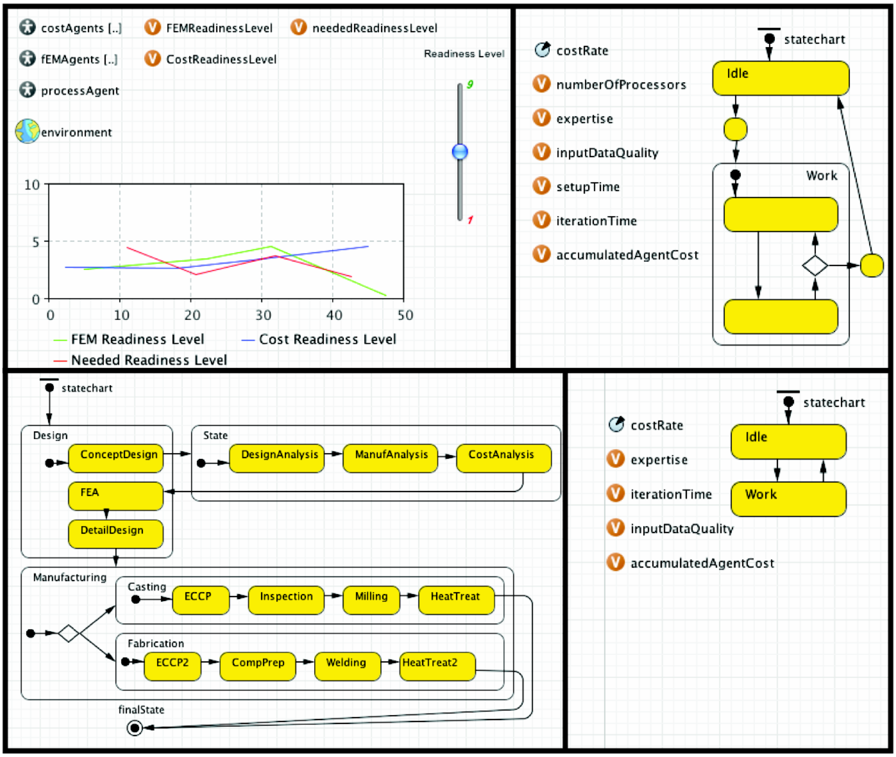

Figure 6. Screen dump of Agent-Based Model of the TORL decision support

The top-left quadrant shows the graphical user interface (GUI) where different curves representing FEA-readiness, Cost Readiness relate to a Needed Readiness Level. This is the equivalent to the TORL Excel user interface from figure 4.

6. Discussion and Conclusions

This paper has shown that modelling the FPD process using agent based modelling and simulation is one way to approach the realisation of a TO decision support. Specific activities and their interaction can be modelled in the PDP. The information exchange and communication occurs between different types of agent, thus enabling the representation of a high degree of a complex process, with a diverse set of activities, i.e. engineering activities, business activities, etc. It has also been shown that micro-level activities and their level of detail can be described at a coarser macro-level of detail using state-charts and variables to represent the behaviour of the activity. This approach enables us to represent a nearly infinite variety of agent behaviour.

Who should do this then? We believe that the individual engineers performing each activity (at micro-level) can contribute by formalising their work process into executable agents in a bottom up approach. However, there is a need to standardise the parameters and variables that are used and searched for.

To conclude, the nature of total offers is that they entail more components (physical artefact, service, software, etc.) than the traditional product construct. Hence the tools for modelling and simulating the extended product construct, i.e. the functional product, require an extended tool set. Here agent based modelling and simulation appears to be an enabler for assessing TRL and Knowledge maturity in a customised FPD-process.

7. Future Work

There are a number of interesting scenarios that is of interest to explore in the directions of future work in this area.

Exploring and modelling the use of planning for upgrades already in the development phase, i.e. if you forecast the life cycle you can plan for upgrades and thus streamlining hardware development in relation to technical developments in R&D phases, meaning that some technologies might be easier to develop and mature at a later stage in the life cycle.

Further, modelling the collaboration between partners in a virtual enterprise, or another value chain collaboration setting, is interesting to explore how partners should align their individual development processes for the benefit of the collaboration. Companies form virtual enterprises not for fun, but because they can utilise their collective capabilities and knowledge to form a better product offering together.

As described earlier, Buxton et al (2006) models aftermarket activities in a value chain. It would be of interest to connect this with the modelling of the product development phase described in this paper to explore more closely the interactions and impact on vice versa.

A challenge with modelling in general pertains to making implicit information explicit so that it can be structured, formalised and thus modelled. This forces developers to formalise tasks to a greater extent than before.

Acknowledgements

The authors would like to acknowledge the financial support from VINNOVA through the Faste Laboratory at Luleå University of Technology, the National Aviation Engineering Research Programme, NFFP 4 (project V4103) and the EC-funded Sixth Framework Programme project VIVACE (Sixth Framework Programme contract number AIP-CT-2003-502917).

References

Alonso-Rasgado, T., Thompson, G., Elfström, B-O., "The design of functional (total care) products", Journal of Engineering Design, Vol.15, No.6., 2004, pp 514-540.

Borshchev, A., Filippov, A., "From System Dynamics and Discrete Event to Practical Agent Based Modelling: Reasons, Techniques, Tool", In Proceedings of System Dynamics Society International Conference, Kennedy, M. (Ed.), Wiley, Oxford, England, UK

Buxton, D., Farr, R., MacCarthy, B., "The Aero-Engine Value Chain Under Future Business Environments: Using Agent-Based Simulation to Understand Dynamic Behaviour, In Proceedings of 8th International

Conference on The Modern Information Technology in the Innovation Processes of the Industrial Enterprises, MITIP, 11-12 September 2006, Budapest, Hungary. 2006.

Ericson Å.,Bergström M., Johansson C., Larsson T., "On the way to knowledge awareness in early design", In Proceedings of the 17th CIRP Design Conference – The Future of Product Development, F. L. Krause (Ed.), Springer, Berlin, 2007, pp 607-616.

Ford, A., "System Dynamics and the Sustainable Development of the Electric Power Industry", In Proceedings of the 13th International Conference of the System Dynamics Society, Tokyo, Japan, 1995

Johansson, C., Larsson, A., Larsson, T, Isaksson, O., "Gated Maturity Assessment: Supporting Gate Review Decision Documents with Maturity of Knowledge Assessment" In Proceedings of the 18th CIRP Design Conference: Design Synthesis, April 7-9, 2008. Enschede, The Netherlands. 2008.

Mankins, J.C. "Technology Readiness Levels", A NASA White Paper, 1996, URL: http://www.hq.nasa.gov/office/codeq/trl/trl.pdf, Accessed: 2007-12-14

Matzen, D., Tan, A.R., Andreasen, M.M. "Product/Service-Systems: Proposal for models and terminology." 16 Symposium DfX, Neukirchen, Germany, 2005.

Nergård, H., Ericson, Å., Bergström, M., Sandberg, S., Larsson, T., Törlind, P., "Functional Product Development: discussing knowledge enabling technologies", In Proceedings of Design 2006: 9th International Design Conference, May 15-18, 2006, Dubrovnik, Croatia, 2006, pp 587-593

Sichman, J.S., Conte, R., Gilbert, N. (eds.), "Multi-Agent Simulation and Agent-Based Simulation", Proceedings of First International Workshop, MABS 98, Paris, France, 1998

Henrik Nergård, Tech. Lic., M.Sc.
Ph.D Student
Luleå University of Technology, Division of Functional Product Development
Luleå University of Technology, E210B, SE-981 87, Luleå, Sweden
Tel.: +46(0)920-49 29 76
Fax.:+46(0)920- 49 13 99
Email: Henrik.Nergard@ltu.se
URL: www.ltu.se/tfm/fpd