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SUPPORTING THE SYSTEM ARCHITECT: MODEL-ASSISTED COMMUNICATION

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System modeling and analysis is used to validate assumptions, increase understanding, synchronize views, and support decisions. By measuring indirect related quantities and commonalities of different modeling techniques in practice we can get an indication of the value of modeling. In this paper, we discuss how to increase modeling value and provide more effective model-assisted communication by understanding critical success factors of modeling. We analyze models used to support production line design at Volvo Aero Norge AS.

Volvo Aero Norge AS manufactures jet engine components for commercial and military engine suppliers. Flight safety is fundamental in the domain which translates to comprehensive component quality and traceability requirements. Long-term engine programs make production line development and process improvements important for staying competitive and maintaining a profitable production that supports the required quality level.

System modeling and analysis is applied to communicate insight between stakeholders and visualize different aspects of production lines and processes. In this paper we present impact factors the architect can use to increase a model's ability to assist communication. We argue how balancing and utilizing the right quantity of these factors increase modeling value.

Keywords: System modeling; system analysis; modeling techniques; critical success factors.

1. Introduction

In a design process the primary responsibilities of a system architect involves addressing customer needs, provide overview of the system and its context, decompose complex problems, ensure consistency, balance and integrity of the design over time (Muller, 2010). To obtain information the architect spends a lot of time communicating with stakeholders in both formal and informal settings. In those settings models are often used to assist communication and help focus the discussion. To increase modeling value it is important to know how to create a model that assists the architect efficiently.

From previous experiences, the author of this paper has encountered situations where models intended to focus and accelerate a discussion resulted in slower and more unfocused discussions. Model assumptions, details and format derailed discussions and wasted valuable time. In successful scenarios the models provided a context resulting in faster and more focused communication. This paper attempts to identify factors that increase a model's ability to assist communication by analyzing a collection of visualizations used at Volvo Aero Norge AS.

Volvo Aero Norge AS is located in the city of Kongsberg, Norway and specializes in high precision fabrication of lightweight shafts, vanes, turbine cases and rear frames. Main customers are Pratt and Whitney, Snecma, General Electric, Volvo Aero Corporation, the Norwegian and US Air Force. Manufacturing processes mainly consist of milling, turning, de-burring, grinding, welding, heat treatment and quality control. To increase process performance and production profits the organization initiates production line design projects and process improvement groups. In this context, descriptions of physical space, time, process flow, cost and product quality are among the most frequent modeling approaches used for supporting decisions and increase understanding.

The author of this paper has over a period of nine months created, applied and gathered models from one process improvement group and several design projects. This paper presents case examples of applied models and research findings with a following discussion on how the findings can increase the value of model-assisted communication.

2. Research Approach

Models were created on demand for project participants and when the author had a need for a model to facilitate communication. After a model was applied in a session the author recorded facts and observations. A total of 21 visualizations were recorded after being used with stakeholders.

The approach to uncover success factors has consisted of three parallel paths. The first has been to record observations, impressions and determine if a model was a success or failure. Dividing the model pool into two groups provided the ability to search for patterns and tensions between successful and unsuccessful models. Observations and impressions were recorded randomly to find clues that could later lead to qualitative discoveries. The second path focused on recording quantitative facts about the models and environment. Type, time used to create the model, number of viewers, type of viewer, tool used, items of interest are examples of facts recorded into a matrix. The matrix was used to search for patterns by applying simple filtering techniques in Excel.

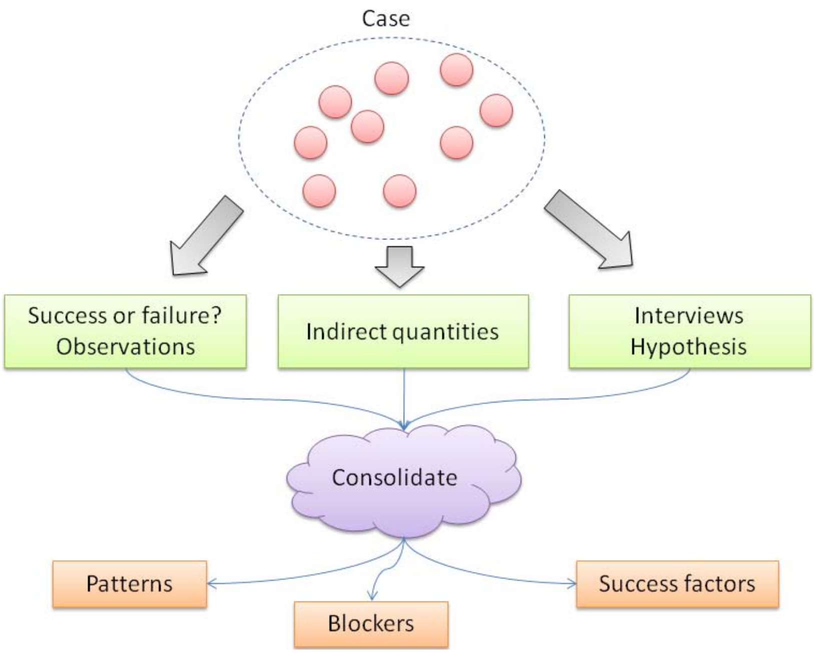

Fig. 1. Research approach.

Criteria for determining the success level for model-assistance relates to the architect's primary needs when using a model with stakeholders:

— Did the model assist in answering the question or set of questions?
— Did the model enable the architect to accelerate discussions?
— Did the model enable the architect to communicate the right information?
— Did the model enable the architect to communicate accurate information?

The third path has been discussions and interviews with exposed stakeholders. Feedback from taking a second look at models and discussing theories have been important to gain information from different perspectives.

Case examples

The author of this paper works in the department of technology, research and development. Responsibilities include assisting machine investment projects, automation projects, process analysis and factory layout. Models included in this research originate from participating in active projects for nine months. This chapter introduces the reader to 21 models used, their purpose, setting and contribution.

Visualizations of physical space are frequently desired in production line design projects. Figure 2 shows a selection of 3D images and 2D AutoCAD drawings created to assist the author in visualizing production concepts and gather

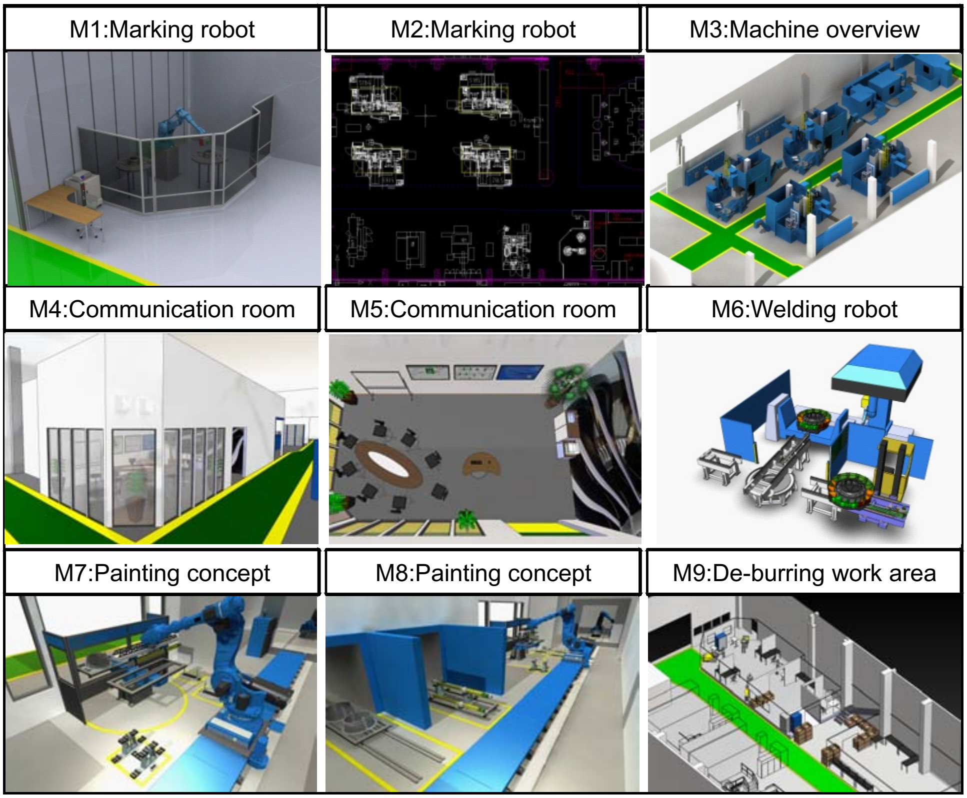

Fig. 2. Visualization of space.

requirements from active stakeholders (Pennotti). M1 visualizes a setup for a robotic product marking system. M2 provides a 2D layout of the shop floor. The model was used to discuss position for the setup and the setup itself in a meeting with representatives from management, technical department and operators.

M3 displays a selection of machining centers and was used in informal settings to assist discussions. M4 and M5 are pictures used to describe a concept for a communication room for operators and managers. The purpose was to visualize the room and to deliver a sketch to the building department for a price estimate. The images were created from discussions with stakeholders. M6 was used in an investment proposal presentation to managers in Volvo Aero Sweden. It was used to visualize a potential solution.

M7 and M8 show renderings of a robotic painting cell concept. The images were used to communicate the concept itself but also as a tool to extract requirements from stakeholders. The 3D model was incrementally created during the project using SolidWorks and was shown in a final presentation for an automation feasibility study.

M9 shows a work area for manual de-burring and inspection of small turbine cases. EHS (Environment, Health and Safety) and logistics were raised as issues in that area so a model was created with the operators to capture their needs and observations. This model is the result of three iterations and will continue to develop as more stakeholders get involved.

Visualizations of flow are often generated to describe how something is done or how information flows. Figure 3 shows three models that visualize flow of statistical information and was created to communicate how different stakeholders can use that information to affect production processes at different levels. Models of abstract nature are frequently used among engineers to describe flow of data between software.

Visualizations of product status have been created in a process improvement group where the goal was to create a robust production process by uncovering and eliminating sources of variance. Production processes are divided into operational stages where the final geometry is created step-by-step. M13 was created for a discussion on the subject of process capability and visualizes 13 critical part measurement points relating to a turning operation. The discussion was conducted in a casual environment with a group of seven project participants. The model was plotted on a large piece of paper (90 cm × 110 cm) and laid on a table. Enlarging the plot was done to make the model viewable for all the participants simultaneously. M14 is the short management summary with the biggest challenges from that operation. M15 is a plot from a statistical program used to explain the measured xz location of nine holes on a turbine case.

M16: Input application is a visual basic application created to enable operators to record and view manual measurement data. Several versions were launched and tested by the operators and their feedback was incorporated into each new version. The model is still active and will continue to evolve from user experience.

M17: Probe comparison is a series of graphs showing the results of three-part measurement probes measuring the same outer and inner diameter on a calibration tool. The model was used to visualize the difference between the probes and the CMM machines (Coordinate Measurement Machines).

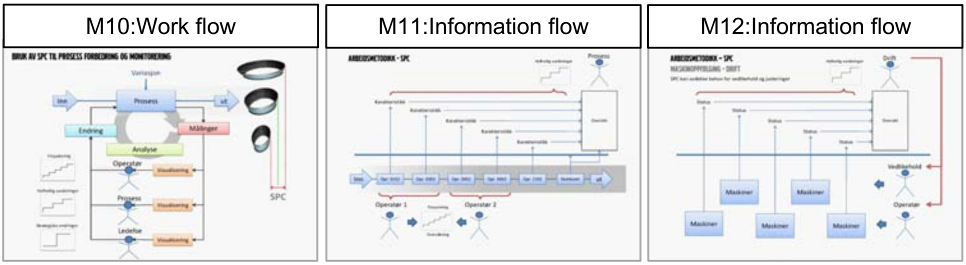

Fig. 3. Abstract models of work flow.

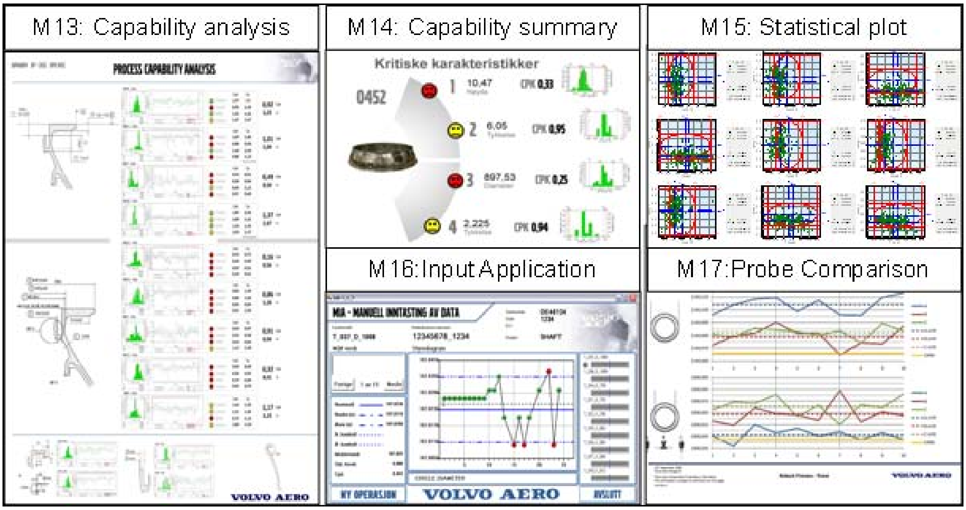

Fig. 4. Visualizations of product status.

Supplementary visualizations have been created in the process improvement group. M18 to M21 are all related to the making of a maintenance program for a group of machines. M18 shows a segment of a PowerPoint presentation. The presentation was made to emulate a web page for maintenance tasks. The blue (online version only) buttons are hyperlinked which enable the presenter to show functionality during the presentation. M19 and M21 are examples of the maintenance instructions

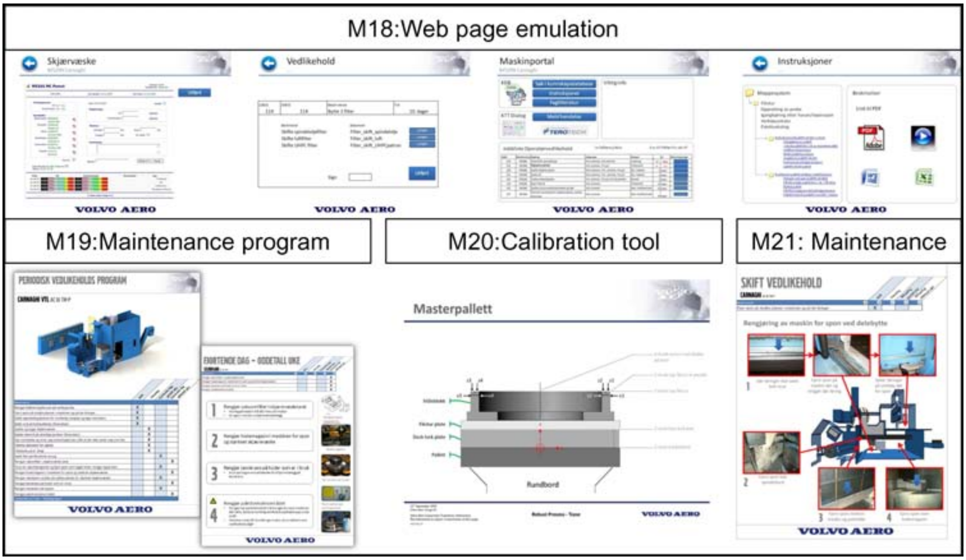

Fig. 5. Supplementary visualizations.

Table 1. Summary of impact factors.

Total recordings	21		
Visualizations of space	9	Visualizations of flow	3
Visualizations of product status	5	Supplementary visualizations	4
Tools used	PowerPoint, Excel, Visual Basic, SolidWorks, AutoCAD, qs-Stat		
	Min	Max	Average
Times used with stakeholders	1 session	5 sessions	2, 7 sessions
Time used to create	1 h	20 h	5, 1 h
Number of viewers	1	40	15, 7
Number of iterations	0	20+	3, 1

created for the operators. M20 is a description of a calibration tool for machines utilizing IPG (In Process Gauging). It was used together with M17: Probe comparison to assist describing the tool.

Quick facts. Table 1 shows a small summary of quick facts of the models included in this paper.

3. Research Findings

Success factors. Visualizations of space have in all scenarios accelerated discussions in terms of providing a setting where all stakeholders see the same image of what is being talked about, thus little time is wasted on explaining the model. The two-dimensional AutoCAD drawing is a well known model of the factory that many stakeholders have seen and waste little time to understand. A pattern for all models is that there is a threshold for when the presenter is able to ask relevant questions. From interviews and discussions two factors have been talked a lot about: *close to reality* and *instant recognition*. Close to reality means that whatever the model is, it looks similar to real world items or environments. Instant recognition signifies that the model you are presenting is of a type or display elements that are instantly recognized by stakeholders. Utilizing the two factors when making models has reduced the time needed to get an answer.

Personal relevance has also been discussed as an important factor. Personal relevance signifies that what you are presenting impacts the stakeholder in some way, for example, M9 — de-burring work area where the operator sees a picture of a safer workplace. Another example of using personal relevance is to utilize formats known to the stakeholder because of profession, education or work environment. Personal relevance impacts the stakeholder or utilizes known elements that trigger faster response and often more serious answers.

In 65% of the cases a model was used in combination with other models capturing different views. For example, M1 and M2 — marking robot which display how the setup looks in combination with its location. M13 — capability analysis combines sketches with run charts that display a development over time. M18 — web page emulation shows many different views of a web page. *Multi-view models* help formulate questions by providing the right context and have excelled in open discussion where the outcome is unknown.

An example of a model used for an open discussion is M13 — capability analysis. The model was plotted on a large piece of paper (90 cm × 110 cm) and laid on a table. Large areas around the part sketches were left empty. When the group started using the model the run charts were investigated and questions started flying. Project participants used the *empty space* around sketches to draw tool paths to understand more about how the geometry was created and reason about how different measurement points were connected. Providing drawing space together with part sketches and run charts invited people to participate. The drawing space was not put there intentionally but had a positive effect on the output of the discussion because it enabled users to add views and follow treads of reasoning (Muller, 2004).

M18 — web page emulation was created to imitate a solution and also encouraged *participation*. Stakeholders provided requirements of great detail after navigating a few slides. Participation requires the stakeholder to use or do something that brings forward work procedures or details obvious to the stakeholder but not the architect. Many aspects of M18 were based on *assumptions.* Those assumptions resulted in feedback which either confirmed the assumption or corrected it. Assumptions have proven to be very useful for provoking feedback and enlighten the architect on matters that could lead to serious design flaws. 3D images (M1–M9) have also contained assumptions based on best guesses and provoked the same effect.

M16: Input Application and M18 have *dynamic properties*. The user interacts with the model and the model provides feedback. Another type of dynamics is animation which combines time with images. No animations have been made in these projects but the author of this paper has created animations for earlier projects using SolidWorks animator. Dynamics produce a similar effect as participation by showing more functionality or information than a static image. Animations make it easier to present complex information in a time efficient manner.

73% of the models were used more than once. 91% of those models were updated or modified after use. Especially 3D models (ex. M1, M5 and M9) evolved from meetings with stakeholders from different departments. M9 — de-burring work area is a good example of how the credibility of a model can increase from receiving information from stakeholders with different concerns. M9 is the result of five *iterations.* The initial model was created in front of a meeting based on requirements from the building department. After meeting with a group of five stakeholders, it was determined that the proposed solution did not cover all their needs and uncovered logistical challenges. Two informal discussions with operators conducted in the current work area created a new potential solution covering their needs as first-hand users. Two more followed that involved the building department and the product

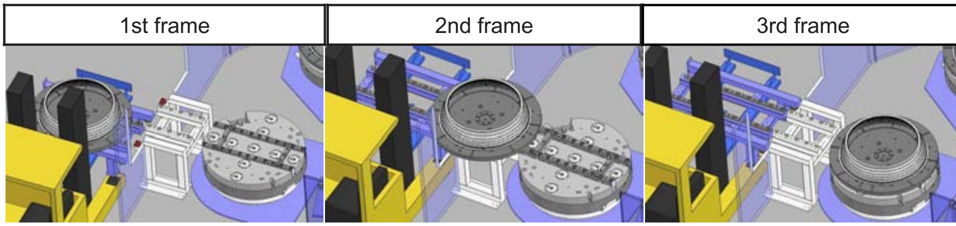

Fig. 6. Snapshots from animation of a pallet change sequence.

group manager. New requirements were added along with new limitations, some included in the model itself and some written down for later discussions.

M19 and M21 — maintenance program was created to illustrate how a possible maintenance instruction could look like. A lot of effort was used on making the model look like a standard. Elements like logo location, page layout, color setup, menu and picture location was important to create a matching series of instructions. M19 and M21 are currently in use in a limited product area and are being extended. After a period the maintenance program will be evaluated as a candidate for a corporate standard. Models of descriptive nature like M19 and M21 have proven to be powerful because they leave an imprint.

Some types of models have been easier to use in different scenarios and group settings. 3D visualizations excel in all cases because they have a wide appeal and are easy to understand. Statistical plots require some domain knowledge and have been harder to use in groups of many different stakeholders. Abstract models excel in small groups of engineers and managers because they are used to seeing, interpreting and accepting abstractions.

Challenges and blocking factors have a presence in every model made so far. They have appeared in three stages: creation, during use and repercussions after use. When creating a model the modeler is faced with a balancing act of *format, effort and purpose*. The three factors influence the value of the model in terms of cost versus benefit. A model can answer any question with 100% reliability, but the effort of making that model may, in terms of time and resources spent, exceed the value of answering that question with such accuracy. Finding this balance has been a challenge both for the author and his managers.

During use, *details* in models are a common source of noise in discussions especially in groups. An example of small triggers that can completely de-rail a conversation is color. Notice that all machines and robots in models are blue (online version only) (M3, M6, M7, M8, M19 and M21). In some of the early attempts to use 3D models as assistance, an ABB robot was shown in its stock color (orange, online version only) and became an immediate source of attention. Volvo standards dictate that machines are colored after a specific code. When irrelevant details receive a lot of attention, like the robot color, *guidance* is an important tool to regain focus. Guidance means that the presenter either ends or re-channels distractions by, for example, saying that the color will be changed to the next session. Guidance can also be used as a preventative tool to prepare stakeholders for the coming model. M7 and M8 — painting concept, contain a lot of assumptions which were presented immediately and did not receive unnecessary attention.

Unfamiliar formats are a natural source of attention in meetings. M15 — statistical plot contains nine *xz* plots on one A3 paper and has previously been visualized in 18 run-charts, two for each hole. Showing *xz* plots eliminates time development in the sense that measurements are not shown sequentially but as a group. The first time this format was used, it took approximately 5–10 minutes before discussing where the actual hole locations started. The same has been experienced when using diagrams of abstract nature like M10–M12 — information flow. A new format needs explanation and credibility before it is accepted.

The *number of stakeholders* having seen the models varies from 1 to 40. M13 — capability analysis, M14 — capability summary, M19 and M21 — maintenance program are examples of models that have been used with many simultaneously and with a few at the time. When M13 was used in a small group its details and run-charts were thoroughly discussed and a lot of new questions resulted in progress. The same model was used in a presentation for 30 people. In that situation the model served as an example of how the group had worked and how a process overview could be made. M14 was a summary of the new focus areas after using M13. M19 and M21 were shown in the same presentation as summary of what had been done and how a corporate standard could look. This time the models did not result in progress or new requirements but had a synchronizing effect. This is a pattern for using models in groups. In groups of 2–5, discussions and gathering requirements has been very effective. In groups of 6–12, this activity gets harder and is best suited for discussing more general topics and presenting ideas. Groups of more than 12 are best suited for providing information and summaries. The group classification is based on that every group consists of stakeholders with different roles and concerns since this has been the case in 90% of the group sessions.

As mentioned, the effect of some models become apparent after use. M6 was made for an investment proposal and first used in Sweden. The investment was approved and then shown to the product department. M6 — welding robot displays a material handling system in front of a welding robot of the same type Volvo Aero already utilize. This machine covers a large area in the welding workshop. Adding one additional machine together with a material handling system would completely divide the workshop in two. So when the product department saw this drawing they started commenting that this setup was useless. What they did not know was that this model was created in a hurry (1 hour) to visualize a principle to management. Its purpose was never to show a possible layout. This is one example of repercussions that are hard to predict.

In 11 of the cases, parts of the model have been re-used in another situation or in the making of a new model. There are two ways to describe *re-usage*, opportunistic reuse and planned reuse. Opportunistic reuse has in every case resulted in decreased

Table 2. Summary of impact factors.

Impact factors	Explanation	Example
Close to reality	Close to reality means that whatever the model is, it looks similar to real world items or environments.	3D models/ images
Instant recognition	Instant recognition signifies that the model you are presenting is of a type or display elements that are instantly recognized.	Part sketch
Personal relevance	Personal relevance signifies that what you are presenting impacts the stakeholder in some way.	Workplace
Multi-view models	A model used in combination with other models capturing different views.	Time and space
Participation	Participation requires the stakeholder to use or do something.	Web page emulator, drawing space
Assumptions	An approach to make a complete picture of a solution even though all facts are not known.	Concept visualization
Iterations	Model created from several iterations.	Concept visualization
Format, effort and purpose	A balancing act to ensure the right format is chosen for the right purpose created with the right amount of effort.	All models
Details	Details signify the effort to utilize the right amount and type of details in models.	Color of robots
Guidance	Is the effort of focusing discussions towards a specific topic.	All models
Number of stakeholders	Number of stakeholders involved.	All models
Intention	Communicate the intention with the model to avoid drifting conversations, unwanted expectations and repercussions.	Welding robot
Dynamic models	Models that enable the user to interact with the model, or animations.	Web page, pallet change

creation time, but planned re-usage has been more difficult to use. Items designed to be reusable increases the initial creation time with the hope of decreasing creation time of the next model. Examples of planned re-usage that have worked well are some of the 3D models. M3 — machine overview contains a machine that is reused in M19 and M21 — maintenance program. M6 — welding robot was created in 1 hour with SolidWorks and is a result of reused assemblies and parts. Creating that model from scratch would normally take days. The downside to planned re-usage is when a lot of resources have been spent and the model becomes either not fit or requires further attention at the moment of reuse.

Expectation is a side-effect of creating models with stakeholders. In cases where a solution was built incrementally, stakeholders get to express problems and wishes.

Receiving this attention often leaves expectation that something is about to change. If the sessions were performed in connection with a feasibility study there is no assurance that an actual change is going to happen. Being clear about the *intention* can eliminate surprises like the layout issue with M6, irrelevant detail discussions and false expectations.

Tensions and opposites become apparent from summarizing the findings, for instance high level of details as opposed to low level of details or instant recognition versus unknown formats. Table 1 summarizes success factors and blockers discussed so far as *impact factors*. From analyzing a relatively diverse group of models the results are equivocal. Although the level of details is mentioned as a common source of unwanted focus, it also results in discoveries that bring forward important focus areas. The tension phenomenon of too much or too little varies immensely from case-to-case and is relevant for all impact factors.

Balance is therefore a major universal success factor for model-assisted communication. The architect's ability to balance and utilize impact factors that fits to the scenario without using too much resources during creation and use, maximizes the value of the model.

Figure 7 describes elements the architect balances for each modeling scenario. At the top, the architect creates an initial profile of the scenario by quickly analyzing

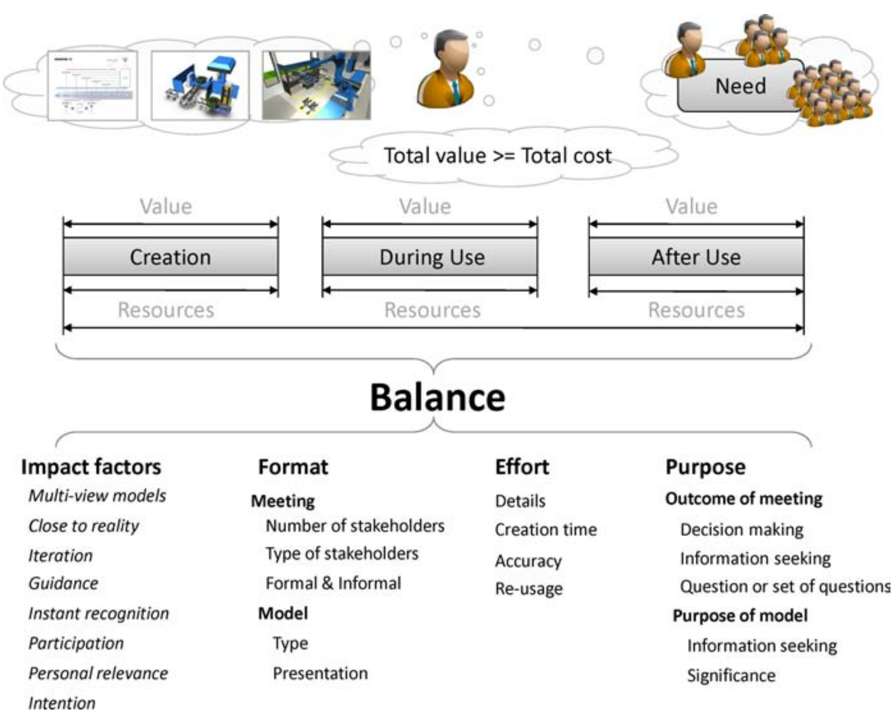

Fig. 7. Balance of modeling effort.

the need, number of stakeholders and possible formats. To finalize the profile for the model the architect evaluates the total cost of making and using the model against the expected value in each step. This evaluation involves scanning through all the subheadings under format effort and purpose and add impact factors to create the wanted effect.

Table 3. Summary of impact factors and their impact on model effectiveness and resources.

Impact factor	Effect of factor	Impact on model effectiveness	Experienced impact on resources
Close to reality	Easy to understand for stakeholder	Faster communication, less misinterpretation, increased accuracy	Increased creation time
Instant recognition	Easy to understand and accept for stakeholders	Faster communication, less misinterpretation	Sometimes increased creation time
Personal relevance	Appeals to ownership	Increases feedback and feedback reliability	Reduces session time
Multi-view models	Creates context for discussions	Provides right amount of information	Increased creation time
Participation	Engages stakeholder	Increases feedback, can uncover new elements	May increase session time
Assumptions	Provokes feedback	Accelerates discussions, helps to answer questions	Can increase session time
Iterations	Evolves model over several sessions	Increases reliability	More resources involved
Format, effort and purpose	Maximizes output of model	Optimizes time and resources spent on making models in relation to model purpose	
Details	Provides right information	Accelerate discussions, increased model reliability	Increased creation time
Guidance	Focuses meeting	Accelerates discussions, channels feedback on the right topic	Reduces session time
Number of stakeholders	Involves the right number of stakeholders	Accelerate discussions, optimizes output of meeting	Reduces session time, may reduce resources involved
Intention	Focuses meeting, provides clear expectations	Accelerates discussions, channels feedback on the right topic	Reduces session time
Dynamic models	Simplifies showing functions and complex information	Communicates the right information faster and more accurately	Increased creation time

One example of utilizing impact factors to create an effect is to reduce the initial cost of the model trough iteration. The cost is reduced by spending little time on making a model and compensate with spending more time guiding and explaining during the first session. After the initial session new insight on the need may or may not justify spending more time on the model. Table 3 summarizes the impact factors, the effect of using factors, and the impact on model effectiveness and resources.

4. Feedback

Feedback from stakeholders confirm that using a model as means to assist communication has in the majority of cases increased the output of sessions. The most important feedback has been that the models used in the projects have provided focused and unambiguous discussions. Unambiguous visualizations synchronize the stakeholders' perception of the problem and eliminate decisions based on wrong assumptions and misinterpretations. Stakeholders also confirm that all the impact factors has an effect on a model's ability to assist communication and that the balance of these factors is important to create models that suits the scenario.

5. Reflection

A model can be defined as any incomplete representation of reality, an abstraction. The essence of a model is the question or set of questions that the model can reliably answer for us (Buede, 1999). There are so many formats a system architect can select to assist communication. This paper presents models of realistic nature used at a small scale in a factory environment. To further explore, validate and elaborate the impact factors and the approach to create balance the environment needs to be larger and the model pool greater. The use of very simple models like paper drawings, more advanced simulations and animations are interesting extreme points that could add insight to the process of balancing model effort. The research also expresses one view of what the value of systems modeling and analysis is and should be compared to similar work.

6. Conclusion

This paper set out to identify factors that can increase a model's ability to assist communication in situations where the system architect seeks to obtain, or communicate insight with stakeholders. Several factors have been identified but tensions and opposites render it hard to conclude with specific success factors and blockers. It suits better to describe them as impact factors that are present in every model but in variable quantities for each scenario, and that the architect's ability to balance and utilize these factors without using too much resources during creation and use, maximizes the value of the model.

Value is created in every step of making and using a model trough, enlightening the architect during creation, use and after use trough iterations and reflection. Balancing the cost of making the model against the expected value in all stages is important not to waste valuable time on making advanced or time-consuming models used to make insignificant decisions.

Feedback from stakeholders confirm that the right use of impact factors enables the architect to create model effects that help stimulate and focus stakeholders towards the purpose of the meeting. Visualizations synchronize perception of the problem and eliminate decisions based on wrong assumptions and misinterpretations. The approach to balance and utilize the right quantity of impact factors is difficult to quantify and is in this paper described as a thought process based on experience and intuition.

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Biography

Even Engebakken received his B.Sc. in Mechatronics from Buskerud University College in 2006 and in 2010 he received his M.Sc. in Systems Engineering from Stevens Institute of Technology. He is currently employed as a Systems Engineer in the R&D Department at Volvo Aero Norge AS.

Gerrit Muller received his Master's degree in Physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a System Architect, followed by two years at ASML as a Manager of systems engineering. He then returned to Philips (Research) in 1999. Since 2003 he has worked as a Senior Research Fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008 he became a full Professor of Systems Engineering at Buskerud University College in Kongsberg, Norway.

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