Increasing the value of model-assisted communication: Modeling for understanding, exploration and verification in production line design projects

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Abstract. Modeling and visualization is a common tool in the systems engineering process used to validate assumptions, increase understanding, synchronize views, and support decisions. The architect can apply models to support different purposes through all phases of a project. In this paper, we analyze model usage in production line improvement projects at GKN Aerospace Norway (GAN). We apply modeling in the understanding phase, exploration phase and verification phase of various projects. Our goal is to identify factors in the applied models that affect the models' success rate. Further, we explore how the importance of the identified factors varies in the different modeling phases. We also discuss how much effort the architect should invest in model creation.

Among the impact factors we discuss are: a models *ability to be instantly edited*, visual attributes like how *close to reality* the model appears, a model's *level of details* and *assumptions*, and how *personally relevant* the model content is. Observations and feedback captured during this study indicate how the importance of each identified impact factor varies relative to the modeling phase. We also suggest that the resources spent on model creation should be in accordance with the intended value of the output from the model.

By understanding how and when to use the impact factors discussed in this study, the architect will be better suited to make the proper design choices during model creation, and be able to provide more effective model-assisted communication.

Introduction

Modeling and visualization. Muller states that when new projects are started, the problem is often ill defined and only some ideas exist about potential solutions. The goal of the architecting effort is to change this situation into a well-articulated and structured understanding of both the problem and its potential solutions [1]. Modeling and visualizations are a commonly used tool to reach this goal. INCOSE has described modeling as one of seven steps in the SIMILAR system engineering process [2]. Bellinger defines a model as "a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system" [3]. It is important to bear in mind that the model does not achieve a goal by itself, but it supports the user in reaching a goal. The purpose of a model is to:

- increase understanding of a problem
- synchronize views

- support the project in reaching the right decisions to achieve the project goal [1]

By itself, the modeling approach is a process going through different phases as described by Muller [1] (Figure 1).

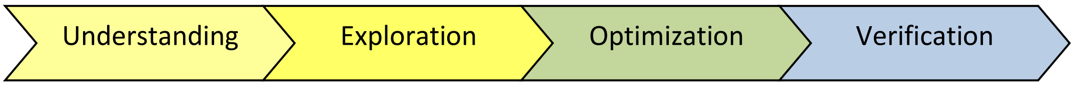

Figure 1. Modeling and Analysis approach

In this paper, we will analyze the use of models for understanding, exploration and verification in production line design projects conducted at GKN Aerospace Norway (GAN). We have left out optimization phase because the scale of the projects investigated is relatively small, and optimization is included in exploration of alternatives. Models can be used in different ways and formats. Our goal is to identify success factors in the models used and explore how the importance of these factors varies in the different modeling phases. We will also discuss how much effort one should invest in model creation relative to the value gained in return.

Case. GAN is a manufacturing company specializing in production of high precision components for commercial and military jet engines. The business situation is characterized by a stable market with long-term contracts and stable production quantities. Despite the stable market, it is vital to maintain a leading position by constantly improving the production with more time and cost efficient equipment, better processes and resource utilization, and more robust solutions. The primary author of this paper is employed in the R&D department, and is responsible for layout planning in production line improvement projects. Typical stakeholders in these kinds of projects are production department leaders, upper management, machine operators, building department, and safety representatives. Common areas that need to be addressed are; physical space, usability, workflow, cost, time, and safety. The stakeholders all have different concerns and objectives. A major part of the work tasks concerning layout planning is to communicate insight between stakeholders and visualize different aspects of production lines and processes. In these settings, models are often used to assist communication and focus the discussion. Challenges are often:

- Stakeholders pulling in different directions
- Stakeholders that do not share a common understanding of problem and goals
- Knowledge gaps between stakeholders
- Work sessions ending without decisions made and unclear conclusions on future work.
- Potential problems need to be detected early in the development process to prevent expensive and time-consuming setbacks in critical project phases.

The primary author of this paper has experienced both positive and negative effects from applying modeling in layout projects. Positive effects can be more efficient meeting sessions with engaged stakeholders that reach conclusions within a given time by focusing on the models presented. In negative cases, the models distract attention from intended area of focus resulting in inefficient sessions and little progression towards the goal. Engebakken [4], Rypdal [5] and Polanscak [6] have previously conducted research on model-assisted communication at GAN (former Volvo Aero). The focus in Engebakken's paper was to increase modeling value by identifying and understanding critical success factors of modeling. He presented a list of impact factors for model use in general. Our paper builds further on the defined impact factors by focusing on how the project phase influences the importance of each impact factor. We also discuss how the balance between the impact factors can increase the models value, and we reason about the amount of effort the architect should invest in model creation. With this increased insight in modeling success factors, the model creator will be better suited to make the proper design choices. This again will increase efficiency and success rate.

Research Approach

Over a period of 9 months we have created and used models on demand from stakeholders, or when we have seen a need for models to assist communication. Our approach is described in figure 2. The process starts with a case that requires some kind of modeling effort. Before we create a model, we identify the stakeholder's core concerns and objectives, and determine the models scope and format. Then we create the model and apply it in a work session. During the work session, we observe the stakeholder's response to the model. The observations could be direct comments to models, expressions of feelings toward models, engagement by stakeholders pointing towards models, the time models stayed in focus, focus turning away from intended topic etc. We collect the observations in a logbook along with quantitative data from the model creation. Quantitative data is here model creation time, tools used, number of iterations with stakeholders during creation etc. We also ask the stakeholders for direct feedback on the applied models after work sessions, and log the replays. The process is iterative and open for adjustments along the path. We often go back and re-evaluate previous steps when we gain new insight. In this way, we can generate hypothesis concerning impact factors of importance, and test them by scoping new models according to our hypothesis.

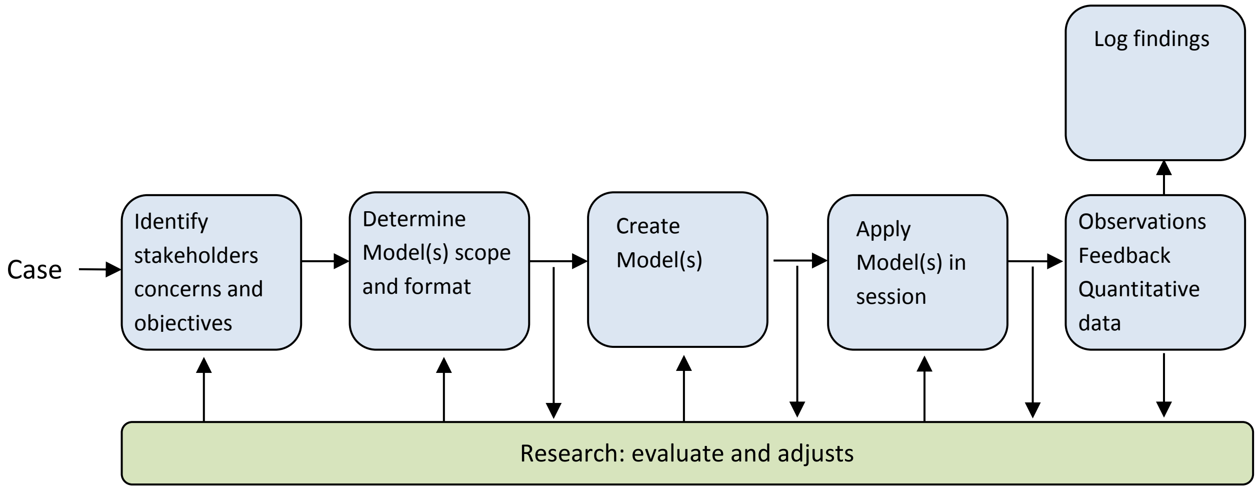

Figure 2. Research approach

Examples of modeling in various phases

The objective of this research is to explore what influence different impact factors have on a models success rate relative to the project phase. For this purpose, models have been used and analyzed in many different projects from start to end. This has mainly been machine investment projects and process analysis. This section is organized in three different project phases; understanding phase, exploration phase and verification phase. In each phase, we present a selection of explored models. In total we introduce the reader to 22 model examples from the different phases[1].

[1] Larger size illustrations of the models can be found at: http://www.gaudisite.nl/IS2014modelsBS.html

Understanding phase is the first step in all projects explored. It this phase the goal is to:

- Gain overview of the current situation or case
- Identify stakeholders concerns and objectives

Figure 3 shows 8 model examples used in the understanding phase. M1 shows a value stream map (VSM) of a production area. The goal of the model was to promote understanding of the production flow as it was at that time, and to identify inefficiencies in the system. Stakeholders present during creation and usage were department leader, technical department leader, quality and process engineers, continuous improvement leader, layout responsible and a VSM expert. Participants created the model as a joint effort on wallpaper. M2 shows a 3D overview of the same area. We used the model as a supplement in the same meeting session as M1. We printed the model on A1 paper format, and used it to assist stakeholders in explaining the process mapped in the VSM model (M1).

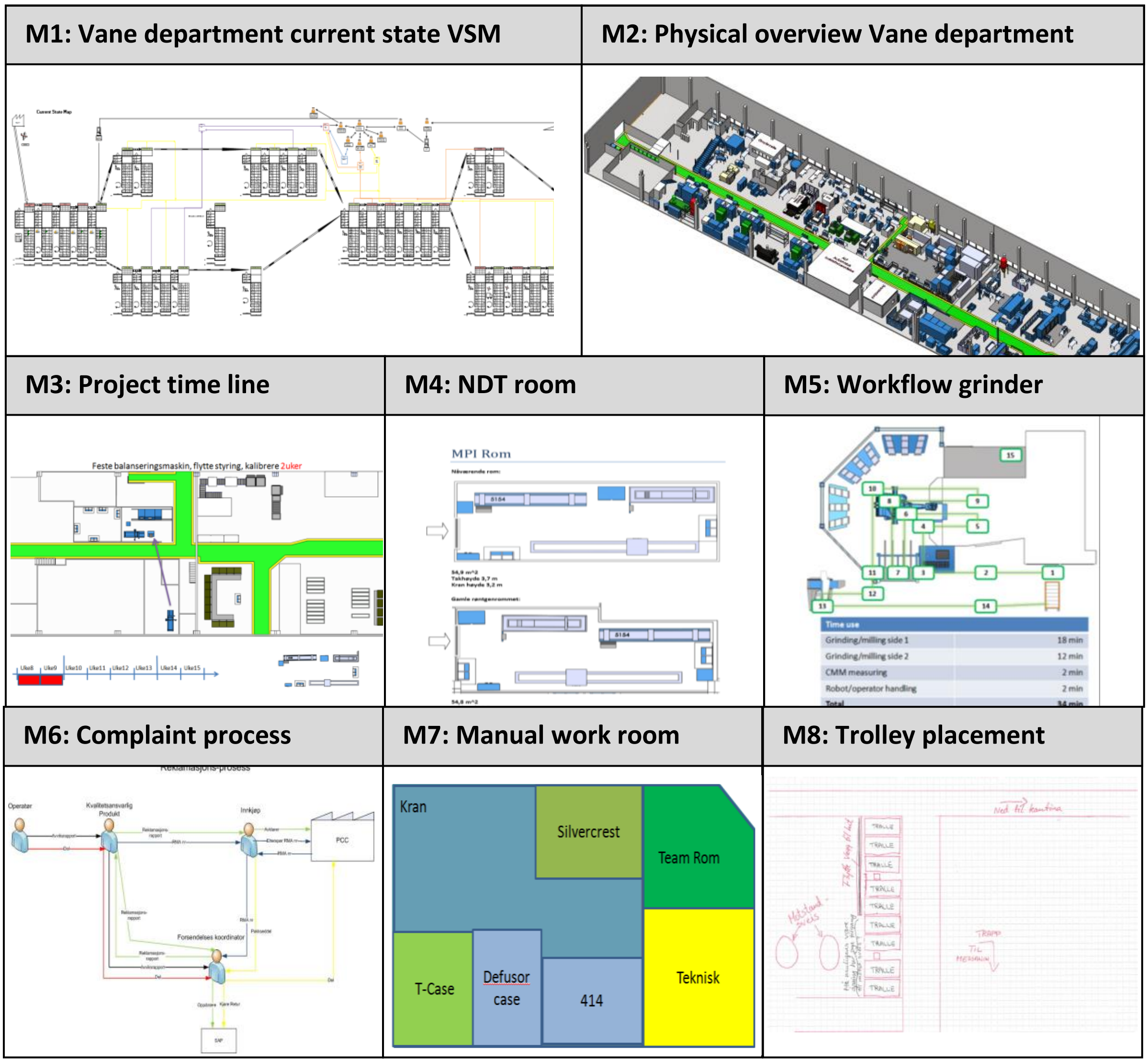

Figure 3. Models used in understanding phase

M3 shows the high-level project plan of a relocating project. The model illustrates the needed physical activities and a timeline for the same activities. We used the model with department leaders from two departments and the building responsible to discuss the high-level project plan. M4 is a low detail model of a production area. We printed the model on paper and used it with machine operators in the production area to promote understanding of requirements for machine usage and placement.

M5 shows the workflow of a machine bought to increase production capacity. We used the model with the investment project leader to gain insight in the machine function, time usage and machine operator interaction points. M6 shows the complaint process used when parts from suppliers do not satisfy GAN's requirements. We created the model based on several assumptions, and updated it incrementally by discussion with stakeholders involved in the complaint process. The goal of the model was to reach a common understanding of the process before exploring process improvements.

M7 shows a low detail layout of a new manual work production area. We used the model with the department leader, the environment, health and safety (EHS) leader and operators to discuss the content and layout of a new dedicated production area. M8 shows a hand drawn improvement proposal for trolley placement in a production area. A production leader used the model to communicate the idea to layout responsible (the primary author).

Exploration phase aims to identify alternative solutions to the investigated case, and to reach a conclusion supported by previous effort. To reach this goal models assist the user in:

- Reaching a common understanding of the case, boundaries and possibilities
- Extracting requirements from stakeholders
- Elaborating on alternative solutions

Figure 4 shows model examples used in the exploration phase of projects. M9 shows a future state VSM of a production department. We created the model during a meeting session with the department leader, the technical department leader, quality and process engineers, the continuous improvement leader and a VSM expert. This meeting was a follow up session where we modified the current state VSM made in the understanding phase to satisfy a goal of 40% reduction in throughput time.

M10 shows an overview of a production area with free space for part storage highlighted. We used the model in a meeting to discuss possibilities to increase the available storage space. Stakeholders were the production manager, the technical leader, and process engineers.

M11 shows the production flow of two core products. M12 shows the capacity of the involved machines in the same production lines. We used the two models in a series of meetings with the goal of improving production flow by streamlining and utilizing machine capacity better.

M13 shows a 3D scan of a production area with a Computer-Aided Design (CAD) model of a new machine integrated. Lindskog et al. created the model as part of a visualization study [7] [8]. We used the model to explore alternative placements for the new machine in a meeting session with the production manager, machine operators, and the investment project leader.

M14 shows a model of a remote Coordinate-Measuring Machine (CMM) system in a welding robot cell. We used the model to explore positions of the CMM equipment relative to the measuring area. Measuring technician, the project leader, process engineers and robot engineers were present during the meeting sessions.

M15, M16, M17 and M18 show layout models from different layout improvement projects.

We used the models to explore alternative solutions with stakeholders from building department and relevant production areas. M15 and M17 were active models that we could edit instantly during meeting sessions, while M16 and M18 were static images. M19 shows an overview of the storage room with most inventories removed. We used the model with operators and department leader in the storage area. The purpose of the model was to engage the stakeholders actively to draw their ideas of the ideal storage room on provided paper versions of the model.

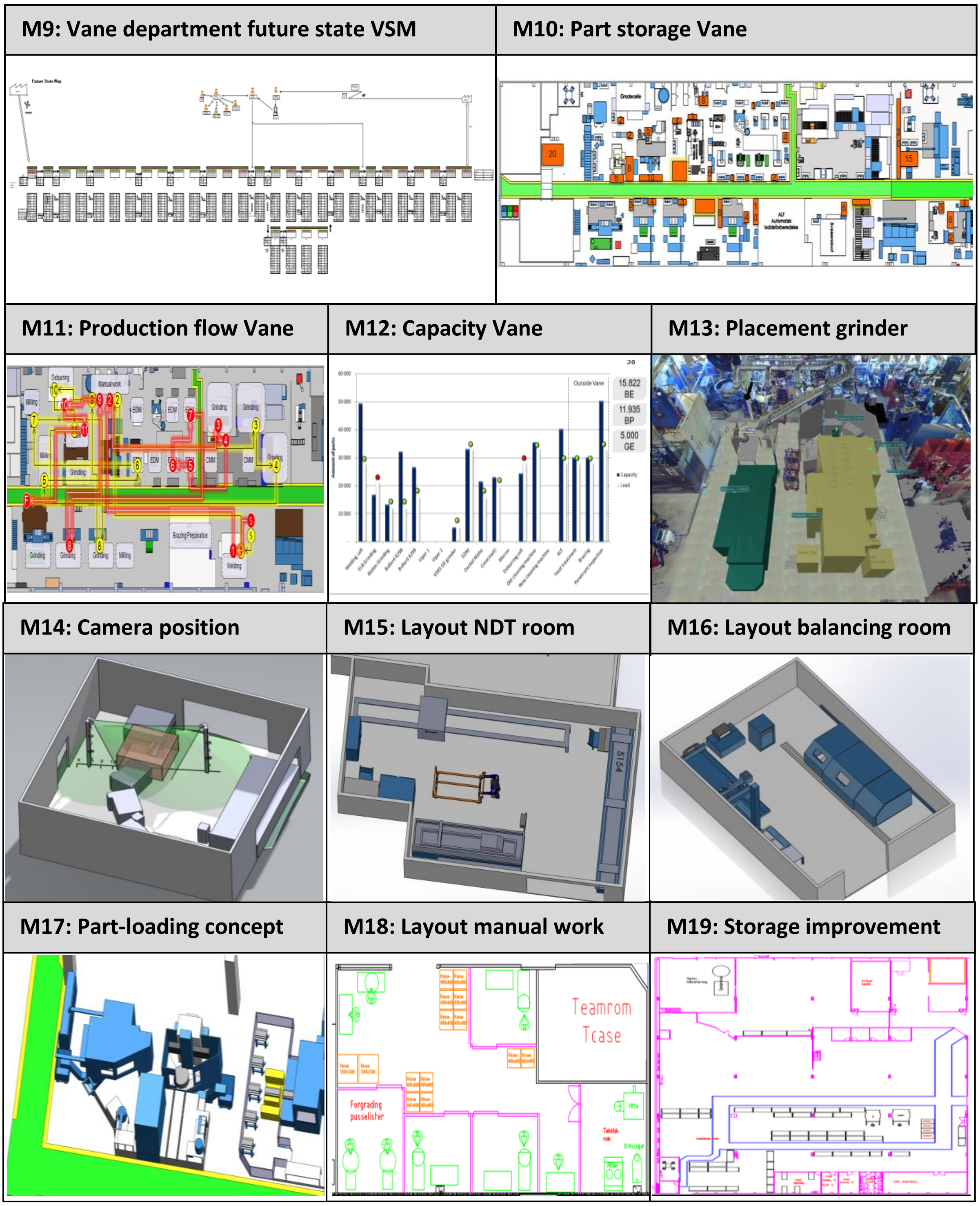

Figure 4. Models used in exploration phase

Verification phase aims to prove that the solution derived from previous effort satisfies the requirements and stakeholder objectives. Modeling in this phase should ensure synchronized views and provide a multidisciplinary view of the solution. Figure 5 shows case examples from the verification phase.

M 20 shows a machine in a new position. The goal of the model was to verify that it was enough physical space for the machine, and to confirm the solution with the responsible stakeholder before actually moving the machine.

M21 shows the placement of a new machine relative to a existing machine. The goal of the model was to verify that it was possible to place two trolleys between the machines. We used the model on paper in the production area with machine operator and the department leader.

M22 shows a verification model of a machine placement made by taping the corners of the machine on the floor in relevant production area. We used the model with the machine operator, electrician, and plumber to verify the placement and prepare for installation.

M20: Machine placement	M21: Machine placement	M22: Tape on floor

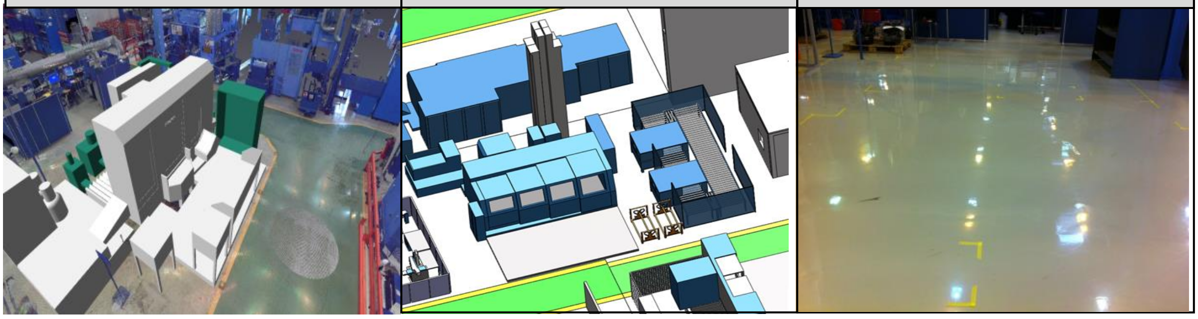

Figure 5. Models used in verification phase

Summary. Table 1 shows quick facts from the models included in this paper.

Table 1 Quick facts from case examples

	Understanding Phase	Exploration Phase	Verification Phase
Number of models explored	8	11	3
Average creation time (h)	2,5	5,5	3
Average number of iterations	1,5	3	1
Average number of viewers	4	6	4
Tools used	Solid Works, Power Point, Excel, Visio	Solid Works, Auto Cad, Power Point, Excel, Point Tools	Solid Works, Point Tools

Research Findings

In Table 2 the impact factors focused on are described. The impact factors are derived from Engebakken's study [4], and from the primary authors own experience. Based on the impact factors characteristics we have grouped them into three high level categories. Tensions that are present within each impact factor are also described in the table.
Further, we have organized this section in sub sections for each impact factor. The sub sections cover the importance of the impact factor relative to each of the three project phases. In the end we discuss how to balance the use of the impact factors, and the balance between effort spent on model creation and value gained in return.

Table 2 Impact factors and tensions

Impact factor	**Description**	**Benefit**	**Disadvantage**	**Example**
Visual Attributes				
Close to reality	Looks similar to the real world	Understanding, overview and engagement	Boundaries prominent, time consuming	Physical 3D overview (M2, M15)
Visibility of core message	Clear message in models	Straight to the point	Other aspects can be forgotten	Timeline (M3)
Content of model				
Level of details	Amount and type of details included in model	Credibility of model	Boundaries prominent, time consuming	Physical detailed model (M16)
Assumptions	Use of "best guess" instead of approved facts	Shorter creation time	Inaccurate model, low credibility	Process as understood (M6)
Multiple views	Showing more than one aspect of a case	Cover different aspects	Distract attention	Time and space (M3)
Personal relevance	Cases that are/ are made relevant to the stakeholder	Engage stakeholders, best solution oriented attitude	strong opinions, time consuming to reach conclusions	Operator workspace (M18)
Model Usage				
Active models	Models that can be instantly interacted with	Instant elaboration on ideas, ownership of ideas	Time consuming	Interactive 3D model (M17)
Guidance	Explain and clarify model choices	Prevent misunderstandings and distraction	Lead attention toward specific solution	All models

Close to reality means that whatever the model is, it looks similar to real world items or environments [4]. In most of the examined cases models *close to reality* resulted in an instant recognition of the model content by the stakeholders. We found *instant recognition* to contribute to a fast common understanding and less time spent on explaining the model.

In the understanding phase, we used models to provide overview and identify stakeholder concerns and objectives. Since it is not always clear what information is needed at this stage, the model creator does not want to waste much time on creating models that in many cases will be discarded after use. Abstract models like M6 and M7 served their task of facilitating discussion on a specific topic without looking like real world objects. For this reason, we found that making models *close to reality* was not of major importance for understanding

In the exploration phase of projects, it is important to engage the stakeholders, and to make the stakeholders actively contribute in the discovering of possible solutions to the problem. We discovered that models *close to reality* made it easier for stakeholders to explain their ideas by referring to objects in the models. M14, M15, M16, and M17 are examples of models used to facilitate discussion on alternative solutions. We used M17 in a meeting to discuss solutions for a new part loading system. During this meeting, stakeholders suggested many creative ideas and contributed actively by pointing at objects in the model while explaining alternative ideas. This was also the case in M14, M15 and M16. M18 and M19 are examples of 2D overview models used for the same purpose. The 2D models do not look as close to reality, and we observed that stakeholders participated less actively, and came up with less alternative ideas in these cases. M13 shows a model that looks very close to reality. We created this model by use of laser scanning equipment, capturing the production environment at a very realistic level. The model served well for discussing the required free space around the machine, however for exploring an alternative machine placement it was less efficient. The stakeholders perceived the model content as a completed solution, and it was hard to convince them that it was a concept open for improvement. This suggests that for exploration *close to reality* is important up to a certain level, but it is not beneficial to maximize *close to reality* level.

For verification, we also found *close to reality* to be an important factor. The purpose of the models in this phase is to communicate a finalized solution, and a visually realistic model gives a strong mental image of what the solution will be like. We used M20 to verify the placement of a machine that was about to be moved. The machine operator that was less used to working with models expressed enthusiastic feelings towards this model. He stated that it was much easier to imagine what his working space would be like in this model compared to a CAD model.

Visibility of core message means that the model emphasizes the project aspect that is meant to be in focus during discussion. Since it is not always clear what information is needed early in projects *visibility of core message* is not a critical impact factor in the understanding phase. M1 is an example of a model we created without a core message. The project group started to create the model by collecting a predefined set of Key Performance Indicators (KPIs) from all operations in the production line. When the participants had completed the model, it showed a representation of the production line that they had to investigate in different ways to discover points of interest. The model itself did not present a core message; however, it was a useful tool for discovering inefficiencies in the production line. M4 is another example of a model we used to increase understanding and discover stakeholder concerns without a core message. The model represents a new layout for a production area, and we presented it to operators in the relevant production area. The discussion that followed emphasized requirements concerning workflow, working procedures, machine requirement, additional equipment, ventilation etc. Without a core message involvement increased, and as a result understanding increased in various aspects of the case.

In the exploration phase, the focus in the models are in most cases connected to one project aspect. M10 is an example of a model we created with focus on free space for storage of parts in one production department. By highlighting free space in a strong color, the free space became the natural point of attention, and it contributed to a more focused meeting. We recorded fewer distractions in this meeting than in the case of M19. We created M19 to explore alternative ways of dividing a storage room into separate receiving and dispatching areas. The model only showed an overview of the storage room as it was. During the meeting, discussion derailed several times into unintended topics like for instance, safety regulations unconnected to the storage room case. As a result, the meeting initiator had to guide attention actively back to the intended topic. This suggests that it is important to consider the *visibility of core message* in the exploration phase.

For verification, this is also the case. We used M21 to verify that two trolleys could be placed between a new and an old machine. The model clearly illustrated this, and the department leader accepted it as an efficient verification.

Levels of details mean the amount of details included in models. *Detail level* of the models used in the understanding phase range from low to medium. Without a clear understanding of problem and context, the benefit of adding details is limited, and the creation time increase. M8 is an example of a hand-drawn model created in a short time that communicates a message efficient with a limited *level of details*. However, when we applied models we discovered that discussions quickly got down to a detailed level. For example, M6 emerged from a simple high-level model to a detailed description of a process through 3 interactions. This implies that details are of importance in the understanding phase, but they should emerge from stakeholder interaction and they do not need to be in the initial models.

In the exploration phase, *level of details* is in many of the case examples closely connected to the *close to reality* factor. A model *close to reality* usually also include a high *level of details*. For example, M13 looks very similar to real world environments and it thereby includes many details. The advantage of this is that credibility of the model is high, and it is harder to forget details like ventilation shafts and stored production equipment when exploring possibilities. The downside is that these details often act as boundaries that prevented the stakeholders from seeing alternatives. On the other hand, too few *details* can result in rejection of the model. M10 is an example of a model that in an earlier revision was rejected by the production manager because it included too few *details* and thereby did not represent a true image of the part storage situation. This implies that a certain *level of detail* is required to get efficient discussions, but a high level might prevent exploration of alternatives. M9 includes many production details without the close to reality factor. In this case, we experienced that *guidance* was critical for taking advantage of the high detail level. Without a presenter guiding the stakeholders through the model, the details would have contributed to confusion rather than increased understanding.

For verification, the effect of high *detail level* is positive in all case examples. The models represent a solution, and more details make it easier to verify the solution to the stakeholders.

Assumptions refer to the use of "best guesses" rather than facts during creation of models.
In the understanding phase, we use *assumptions* in M6 to create a baseline for discussion. The model's purpose was to assist the creator in receiving an overview of a process that had not been described in details earlier. We made the first version of the model based on a vague notion of how we thought the process worked. By creating a quick model and discussing it with one of the stakeholders connected to the process, we identified shortcomings in the model and adjusted it. With two more iterations, the model included few *assumptions* and both the credibility of the model and our understanding of the process had increased significantly. M5 is another example of a model we created based on *assumptions*. It was easy for the stakeholder to pick up the topic of the model, and fill in the information that was missing or unclear. The advantage of using *assumptions* is that creation time is shortened compared to collecting facts up front. This is of importance in the understanding phase where models often are used for a short time to increase understanding on a topic, and then discarded.

In the exploration phase, we found that model creators should use *assumptions* with care.

Extensive time can be spent exploring alternatives based on *assumptions* only to discover later on that the assumptions were wrong. An example is M17 that we used to investigate alternative part loading solutions for a machine. We assumed that the truck delivering parts to the machine could dock to the machine from both sides. We spent three meeting sessions presenting different concepts solutions before we discovered that this *assumption* was wrong, and we had to discard all of the proposals. To avoid instances like this we should have spent more effort in the understanding phase to capture a better overview of the case. Verification models should be based on facts, and *assumptions* should be reduced to a minimum.

Multiple views show a case from more than one perspective, like time and space. In the understanding phase, we discovered that *multiple views* were an effective impact factor. An example is M1 and M2. A external VSM expert not familiar with the production facilities at GAN created M1 together with a project team providing information. During creation of the model, ambiguity caused interruptions to the meeting flow several times. In these cases, the physical overview model (M2) was a useful tool for explaining the parts that were hard to understand in the VSM (M1). By using the two models parallel, the meeting efficiency increased and misunderstandings were prevented. M3 is also an example of *multiple views* usage. In this example, we present both time usage and physical actions in the same model. We used the model to explain the high-level plan of the project in a step by step presentation. It provided the project group with a common understanding of the project goal and at the same time explained why the project would take a longer time than expected.

For exploration of alternatives, *multiple views* could be beneficial or not. In the case of M11 and M12, it was a clear benefit to see the case from two perspectives. M11 show the production flow of two products, and M12 shows a graph of the machine capacity in the machines from M11. When exploring different improvement proposals to the production flow, the effects could be seen in M12. This gave a more complete picture of cause and effect. We could also have included other views like transportation time etc to obtain an even more complete picture. In cases like M10, we have gained understanding of the problem in an earlier project phase, and the exploration is connected to one aspect. In this case, storage space for parts is sufficiently covered by one view only. We can say that in the exploration phase the importance of *multiple views* is dependent on the project type.

For verification, we found *multiple views* to be of little importance in the case examples investigated. The models verify characteristics like machine placement that we found sufficiently covered by one view.

Personal relevance means that the content of the model is relevant to the stakeholder. In the understanding phase, we found *personal relevance* not to be a major concern, but in some case examples it had a positive effect. In M1, the stakeholders knew that the outcome of the model would have consequences for their further improvement work on the production line. This made it *personally relevant* for them to create an accurate model, and they wanted to invest effort to obtain this. In cases like M5 the goal with the model was to increase the model creators knowledge of a process. In this case, *personal relevance* was less important because the model creator knew that the stakeholder possessed the needed information. It was a question of obtaining this information whether or not the stakeholder found it personally relevant.

M15 is a model example of *personal relevance* in exploration of alternatives. We used this model to explore layout possibilities in a production area that had to be moved to a new location. Stakeholders were machine operators, department leader, and building responsible.

The machine operators and department leader had personal interests in making the best possible solution in the new production area, and they spent a lot of effort thinking about solutions. The suggestions they came up with were often more expensive than planned, and the building responsible that kept track of budget had to discard many of the alternatives. Through eight meeting sessions, we discussed a variety of alternative solutions. In the end, stakeholders agreed upon an alternative that everyone satisfied. In the case of M16, the goal was also to improve the layout in a production area. However, in this case the stakeholders were process engineers and investment responsible. The layout was less *personally relevant* for them, and after two iterations, the placement of the machine was decided. After installation, the machine operator complained about too little space for parts storage. This suggests that high *personal relevance* contributes to more engaged stakeholders that again lead to more alternatives investigated, and often better solutions. Negative effects are that the process can become time consuming, and that it is harder to reach agreement.

For verification models, we found *personal relevance* to be of little importance as these are objective models meant for a general stakeholder to approve a solution.

Active models are models the presenter or participants can interact with and edit instantly. M7 is an example of an *active model* used in the understanding phase. We used the model in a meeting with the goal of deciding content of a new production area and the relative size each element in the room would occupy. Little details were available before the meeting. When a model contains many *assumptions*, an instant editing ability in a model provides the opportunity to adjust the model according to stakeholder input. In the case of M7, the discussions during the meeting resulted in a totally changed model that served as a starting point for further exploration. M1 was an active model where all stakeholders participated in altering the model. In this case, the demand to contribute led to engaged stakeholders with motivation to make the model as accurate as possible, which again contributed to a common increase of understanding. These findings suggest that active models are of importance in the understanding phase.

For the exploration phase, we found *active models* to be very beneficial. Input from stakeholders is important to identify alternative solutions. To stimulate the stakeholders to share information we found that *ownership of ideas* and the *possibility for elaboration* were of high importance. M15 is an example of a model we used to explore layout for a production area. We used the model projected on a screen in a meeting room with five stakeholders. The presenter instantly edited the model according to ideas from the stakeholder. This way, ideas that did not work were discarded at once, and ideas with potential could be elaborated further and optimized. We observed that the stakeholders were more engaged, and more focused on finding the "best" solution in this case than in the case of M16. M16 was a static model used for the same purpose. In this case, fewer ideas were suggested and stakeholders had difficulties explaining ideas that deviated from the proposed solution in the model.

Verification models represent a solution, and there is no need for them to be active.

Guidance means the amount of explanation and clarification used to obtain the intended effect of the models. *Guidance* proved to be of high importance in the understanding phase. Models like M1, M5 and M6 are not self-explaining, and explanation of the model during usage is required to ensure a common understanding of the message.

In the exploration phase, the models used in our case examples are more intuitive. Models like M13 and M15 do not require heavy *guidance* to ensure that the stakeholders understand the models intention. In these cases, we found that it was valuable not to use much *guidance*. This avoided the stakeholders to be lead towards a specific solution. We used M14 to explore the measuring area of two remote CMM cameras. We created this model based on mathematical formulas, and contained design choices not visible in the model itself. In this case explaining all design choices up front made the stakeholders trust the model. The discussion that followed was focused on the intended topic of camera positions instead of stakeholders questioning the reliability of the model. This implies that for the exploration phase *guidance* should be limited if the model does not require a certain amount of guidance to be understood.

The verification models we used were more self-explaining, and *guidance* was not of particular importance.

Summary. Table 3 shows the explored impact factors with an indication of their importance relative to project phase. The uniqueness of the field situation at GAN should be taken into consideration when interpreting the findings presented. The findings are based on a certain type of projects, a limited group of stakeholders and one or a few model creators and presenters. The results indicate where to focus the modeling effort during creation relative to project phase. Generally, we can see that the *visual model attributes* are more dominant towards the middle and the end of projects. *Model content* and *model usage* are more dominant in the start and middle of projects. However, the reader should not consider the findings valid for projects in general without further investigation.

Table 3. Importance of impact factors

Project phase / Impact factor	Understanding Phase	Exploration Phase	Verification Phase
Visual model attributes			
Close to reality	Low	Medium	High
Visibility of core message	Low	High	High
Content of model			
Level of details	Medium	Medium	High
Assumptions	High	Low	Low
Multiple views	High	Medium	Low
Personal relevance	Medium	High	Low
Model usage			
Active models	Medium	High	Low
Guidance	High	Medium	Low

Balance

The impact factors described above are present in most of the models investigated. To emphasize the benefits and prevent the disadvantages described in table 2, we found that the composition of the impact factors had a certain influence. For instance, we found that guidance prevented the disadvantages of low credibility in models high on assumptions, and the distraction of attention with multiple views. Active models we found to prevent stakeholders from being stuck in the boundaries of high detail models because we could actively remove details or rearrange the model etc during the meeting session. On a general level, we could say that the impact factors in the *model usage* category can prevent the disadvantages from the impact factors in the *visual model attributes* and *content of model* categories.

Cost versus value

Common for all modeling effort is the question of cost versus value. If the effort of creating a model is greater than the value gained in return for creating and using the model then the architect has to evaluate whether to create the model or not. However, value is a broad term hard to quantify. Muller implies that one way to measure value is in terms of reduced project risk [9]. In production line layout projects, risk reduction can be; increased understanding of current situation and problem, investigation of alternatives and uncertainties etc. Understanding, exploration and verification all contributes to reduction of risk in projects. If we know that increasing understanding on a specific topic, or reaching a conclusion on a project aspect will reduce risk a certain amount, then we can balance the modeling effort accordingly. On a general level, understanding models are typically used a few times before they are discarded. This implies that the creation time should be short for these models if they are to be cost/value efficient. However, if the increased understanding contributes to a significant risk reduction we can justify spending more effort on creating these models. For exploration and verification models, the creation time has been somewhat longer as shown in table 1. Since these models are often more complex, longer creation time is natural. The gain in terms of reduced project risk are also often high for this kind of models, justifying the extra creation effort.

Another factor that should be considered in this context is reuse of models. CAD models like M2 involve a large investment in time and recourses to be created the first time, but once created the time investment will be significantly lower the next time a model is needed from the same area. In a manufacturing company like GAN where layout of the production lines is changing constantly, the effect of having a fast accessible model like this is beneficial. M13 and M20 are interesting examples of models where point cloud technology is applied to shorten the first time creation time significantly compared to a 3D CAD model [8]. The cost/value balance then becomes more positive. Our suggestion is that along with the explored impact factors, *balance* and *cost/value* should be considered before creation of models to increase modeling value further.

Conclusion

The goal of this research was to identify success factors in a selection of applied models, and explore how the importance of these factors varies in the different modeling phases. In addition, we investigated how to balance the use of the impact factors, and the balance between effort spent on model creation and value gained in return. We did this by applying and analyzing model usage in production line design projects at GAN in a period of 9 months.

In total, we explored eight different impact factors in this study. Our results imply that the importance of each impact factor varieties relative to project phase as described in table 3. Generally, we found that the *visual model attributes* are more dominant towards the middle and the end of projects. *Model content* and *model usage* are more dominant in the start and middle of projects. We also found the impact factors to be present in all models, and that the composition of them influences the success rate of the model. However it is hard to conclude with a define set of impact factors and compositions that will be proper to use for model creation in general. The model creation effort should be in accordance with the intended value of the output from the model. One way to measure the value of the model output is by reduction of project risk. If we can reduce risk to a high degree through modeling in a specific case, then more effort can be justified for the model creation.

Our findings can be useful for model creators in similar scale projects and fields. However, a larger scale study is needed to generalize the results to be valid outside GAN.

Reflection and future work

The research presented represents the authors' view of efficient modeling and visualization. Modeling in general can be conducted in a variety of forms, and to serve many purposes. In this study, the focus has been on realistic models for small-scale projects. In this form, we have shown that models add value during creation, in use and for reuse. The importance of the impact factors relative to project phase can be useful insight for model creators in similar scale projects and fields. However, it is hard to connect the models success rate to impact factors and project phases independently. The results could be due to a combination of many factors like the people involved, embedded processes, presentation techniques etc, along with the factors we have identified. It is hard to unravel the exact causes of success and failure. Therefore, the findings should be seen like indications and not conclusive facts.

For further exploration, it would be interesting to see if a larger scale multidisciplinary study could generalize some of the results from this study to be valid in other domains. In addition, it would add insight to the field to explore other impact factors, and to delve into the balance between value added and effort spent on modeling in more detail.

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Biography

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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 manager of systems engineering, returning 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.