# MULTI-PERSPECTIVE VISUALIZATION WITHIN SIMULATION-BASED DESIGN ENHANCED SHARED UNDERSTANDING

**Bart van Zaalen[(a)], Rens Kortmann[(b)], Wijnand W. Veeneman[(c)] Alexander Verbraeck [(d)] Marten Busstra[(e)]**

[(a,b,c,d)]Delft University of Technology - Faculty Technology, Policy and Management
[(e)] NedTrain B.V.

[(a)]b.van.zaalen@gmail.com, [(b)]L.J.Kortmann@tudelft.nl , [(c)]W.W.Veeneman@tudelft.nl,
[(d)] A.Verbraeck@tudelft.nl, [(e)]Marten.Busstra@nedtrain.nl

**ABSTRACT**
Within complex design projects the methodology of Simulation-Based Design (SBD) is regularly used. In the literature critical remarks have been made on the lack of multiple perspectives within such simulations, which creates inefficiency and dissatisfying results of the design. The use of multi-perspective visualization during an SBD process may give participants a better insight in the impact of the design on their own and others' interests. As a result it may create a higher shared understanding (SU) among participants and improve the design. We examined this hypothesis during a design case for a new shunting plan on a marshalling yard, which led to the following conclusion: the addition of multi-perspective visualization enhanced SU among the participants significantly and contributed to a better design result. For similar design cases this approach is expected to be successful too, although small adjustments to the approach and other types of visualizations will be required.

Keywords: Simulation-Based Design, Shared Understanding, multi-perspective visualizations, marshalling yard

## 1. INTRODUCTION

Simulation-Based Design (SBD) is used as a method to support the design of complex systems. This method is experienced to be successful because it enhances shared understanding among actors involved in the design process. Shared Understanding (SU) is of great importance since large technological systems within an environment with a lot of actors are hard to manage due to its complexity, interaction between those actors and their uncertain behaviour (Xia and Lee 2005). Designing a new system in these kind of environments requires SU, defining the problem and solving it through a process of finding a satisficing solution (Simon 1996). In order to increase the quality of design it is therefore also very important to create a high level of SU (Piirainen, Kolfschoten and Lukosch 2000).

Within an SBD process, the tool of simulation is used to solve challenges and meet requirements in a multi-actor environment concerning a complex system (Hengst, Vreede and Maghnouji 2007). Within this methodology the two systems approaches are combined. Hard systems thinking is the approach for the simulation of systems of which a current and desired state are taken for granted and the problem of the system to be designed is structured. Soft systems thinking is the approach for ill-defined and unstructured problems and of which the design process is not goal oriented (Robinson 2001). Simulation is used as a tool to combine these approaches and creates a lot of opportunities; higher acceptance of outcomes, increased shared understanding, better stakeholder involvement, higher quality of the model and its use (Fumarola 2011, Hengst, Vreede and Maghnouji 2007).

To make advantage of these opportunities several frameworks have been developed to structure an SBD process in which the multi-actor design processes leave more room for negotiation, mutual learning and aim for the creation of a higher shared understanding (Huang, Seck and Fumarola 2012).

However, the SBD process still have its limitations. Evaluation of the design process led to the discussion of the actual contribution to a higher level of SU and in the end a higher quality of design (Fumarola et al. 2010). Fumarola et al. conclude that a lack of multiple perspectives exists within SBD processes which can lead to unintended results of the design and opportunities are not used optimally. Just simulating and visualizing from a single perspective reduces important information about the reality since actors try to have intuitions from a single perspective simulation. Important information can be neglected, which is critical to get a better understanding of the system (Bürgi and Roos 2003).

The simulation within an SBD process should therefore be developed with multiple perspectives, so each actor can identify himself with the system and to resolve the limitation encountered within SBD. The enhancement of SU is the main objective in this case.

An experiment has been executed to test whether or not the addition of multiple perspectives within an SBD process creates a higher level of SU. The main research question for this experiment was: *To what extent does the addition of multi-perspective visualization contribute to an enhanced shared understanding in the multi-actor simulation based design process for a logistic process design on a marshalling yard?*

A design for a new shunting plan at a marshalling yard of NedTrain has been used as a case to examine the effect of multi-perspective visualization on the level of SU. The method of case study research has been used because this method gives the opportunity to develop and test new theories within a realistic environment (Yin 2003).

In the next section the construct of SU is explained. The experimental setup, creating multiple perspectives within the simulation and description of the case are discussed in the third section. Results of this research are given in section four, followed by the conclusions and discussion in the final section.

## 2. SHARED UNDERSTANDING

Shared Understanding (SU) is a conjoined term for the mutual knowledge, beliefs and assumptions by a group of actors. The amount of overlap in understanding and concepts of the particular system of study among actors can be seen as the level of SU (Mulder, Swaak and Kessels 2002). Different actors state that the creation of SU will lead to a better performance of business processes within a multi-actor environment (Bondar, Katzy and Mason 2012; Zhao, Yunfeng and Xiaochun 2009). As Mulder denotes; "..shared understanding facilitates working and interacting effectively and efficiently. Interacting effectively and efficiently is possible when the group members use the same symbols and assign the same meanings to those symbols in their interaction processes." (Mulder 1999, p. 1).

Through interaction between actors the SU is affected. During interaction actors exchange information which can be used to create SU. Therefore SU is not on a fixed level, but is always on-going through the interactions between actors (Mulder 1999).

Mulder denotes three aspects of SU; social relation, content and process. During interaction, so also during design processes, actors should have SU on these three aspects (Mulder 1999). Together, this creates an overall level of SU which is important in interaction processes like for example a design process. The aspect of social relation is about who is communicating messages and in what way. Messages from different persons can be the same, but the interpretation by others can differ a lot because of non-verbal behaviour. Interaction about the content should frame the problem so all group members have the same meaning of the problem and the problem area; 'what' are they working on. The third aspect is the process related understanding, for which actors should have the same way of communication, structure of interaction (protocols) and understanding of roles within an actor field. Actors should have a SU on how to work together (Mulder 1999).

Literature and quantitative tests to measure the level of SU are exceptional. However, Mulder developed a quantitative test to measure the level of SU on the three different aspects identified and on the overall level of SU. The test is a questionnaire which has to be filled in by participants of a design or decision making process. They are asked on each aspect on their perceived SU and on the perceived SU among other stakeholders. Additionally the participants can be asked whether or not they think the SU is enhanced. These questions can be used for a pre-test and post-test, before and after a design or decision making process is completed. This test is very suitable for the experiment which has been executed, since a pre-test and post-test can give insight in the enhanced level of SU.

## 3. RESEARCH METHOD

The research was based on the Design Science Research theory by Hevner et al. (2004). By the addition of multiple perspectives in the visualization of the simulation during an SBD process the method can be improved, as proposed by Fumarola et al. (2010) and discussed in section 1. To examine whether or not the addition of multi-perspective visualization contributes to an enhancement of SU a case study has been performed, of which the results can be evaluated and justified to draw conclusions for the methodology of SBD (Yin 2003).

First of all the environment in which the case study has been performed will be discussed. The setup for the experiment on the enhancement of SU is explained subsequently, followed by an explanation of the test methods and organization of the design workshop.

### 3.1. Case NedTrain

An experiment on the enhancement of SU has been performed using a design case at NedTrain, the service and maintenance company of the Dutch train operator Nederlandse Spoorwegen (NS). NedTrain is planning to reorganize its service and maintenance processes. In this process new Technical Centres (TC) are built on four locations scattered around the Netherlands, of which one in Utrecht. The marshalling yard at Utrecht, Cartesiusweg (Ctw), has a remarkable lay-out which can be described best as a bottle and is illustrated in figure 1.

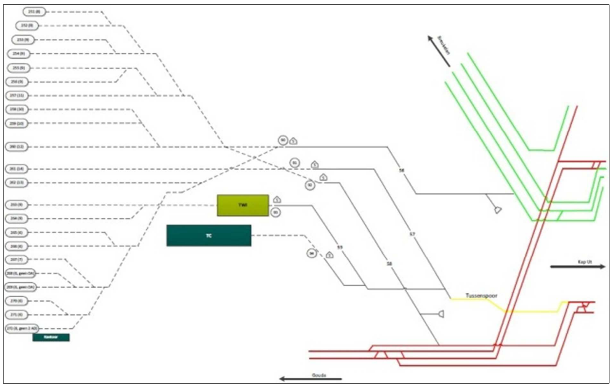

Figure 1: Lay-out marshalling yard Cartesiusweg (Ctw)

The location was already chosen and the tender for the construction project was finished, then thoughts about the risks on the logistical process arose. In figure 1 the location of the TC is the dark green box. Shunting trains from the parking tracks on the left side of the marshalling yard towards the TC creates a lot of problems and conflicts with other train movements, due to the bottleneck at the right side of the marshalling yard. At the same time the requirement for a new shunting plan is stated, which created the opportunity to adjust the shunting process in order to mitigate the risks on the logistic process by the shunting movements to the TC. The design for a new shunting plan including solutions for the accessibility of the TC can be considered as a complex design problem, since the system of Ctw is within a multi-actor environment and its processes and techniques are complex. Therefore this design problem was a good case for the research to be performed on the enhancement of SU within an SBD process.

### 3.2. SBD approach

To structure an SBD process several frameworks can be found in literature. Especially Fumarola et al. (2010), den Hengst et al. (2007) and Robinson (2001) have developed frameworks to structure the design process of an SBD project. Although these frameworks differ from each other, the combination of soft systems thinking with hard systems thinking is found in these frameworks. Due to practical limitations and the fact that the design approach had to align with a reference case which will be exemplified in next paragraph, not one of these frameworks can be adopted. Elements of both the framework of Fumarola et al. (2010) and of den Hengst et al. (2007) are merged into a specific SBD framework for this case study (Zaalen 2013, p. 45).

A part of this framework is focused on the preparation and execution of a design workshop (figure 2). The execution of the design workshop is marked green in figure 2.

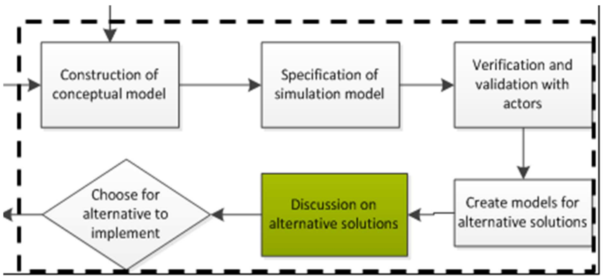


Figure 2: Part of SBD framework focused on the Design Workshop

During this workshop critical actors involved discussed on alternative solutions to implement, in order to improve the logistic process on the marshalling yard Ctw. During this workshop the influence of multi-perspective visualization on the enhancement of SU has been examined.

### 3.3. Tests on enhancement of SU

The enhancement of SU as a result of multiple perspectives within the simulation during an SBD process could not be measured by just the tool of Mulder. These quantitative tests can only measure the enhancement of SU. First of all the tool of Mulder has been used to draw up a pre-test and post-test as discussed in section 2 and examine whether or not there is an increased level of SU. The questions within the pre-test and post-test could be answered on a scale between 1 and 6 (1 = low level of SU, 6 = high level of SU). The post-test improvement questions could be answered on a 7-point Likert scale (1 = high decrease of SU, 4 = no improvement, 7 = high increase of SU).

To identify whether or not the addition of multiple perspectives had a clear influence on the enhancement of SU an observer of a reference case in which an SBD process has been used for the design of a new shunting plan was used additionally to the test of Mulder. Recently an SBD process has been executed on the marshalling yard Watergraafsmeer (Wgm), near Amsterdam. The environment of this design problem was similar to the case of Ctw and was therefore suitable to use as a reference case. In the SBD project of Wgm they just used a single perspective visualization just for the discussion with involved actors and validation of the design. The project manager of this design project has been invited to join and observe the design process to be able to identify whether or not the multi-perspective visualization in an SBD process lead to a higher SU.

Because there was just a single observer, a third method has been used to draw stronger conclusions on the enhancement of SU and the influence of the multiple perspectives hereon. The third method was a post survey, in which participants of the design workshop were presented a list of propositions about the influence of multiple perspectives in a simulation on the level of SU. For each aspect in the pre-test and post-test the participants were presented two propositions, a negative and a positive one on the influence of multi-perspective visualisation on the enhanced SU. An example of such a propositions is: ‘the use of multiple perspective visualization has led to a higher SU on the logistic processes and problems accordingly.’ The participants could answer on a 7-point Likert scale (1 = totally disagree, 4 = neutral, 7 = totally agree).

### 3.4. Design workshop

The design process was drawn up according to the design process as followed in the reference case Wgm and to the possibilities of the case Ctw. Due to human resource and time limitations there has been chosen for a one-off design workshop. Within this 3-hour workshop the critical actors discussed on alternatives for the shunting plan, which were already composed before the workshop in consultation with these actors. The workshop was supported by a simulation, since it is an SBD process. The simulation differed from other SBD processes in the amount of perspectives to be visualized. For each actor the most important KPI or KPIs were identified and visualized using the information from the simulation model.

The visualizations to provide information on actors perspectives were drawn up to the possibilities which were limited due to time constraints and development possibilities of the software used. The behaviour of the system is animated with the visualization of the lay-out of Ctw and train movements on the infrastructure. Several perspectives on KPIs have been visualized by graphs and tables. Figure 3 illustrates the setting of the workshop.

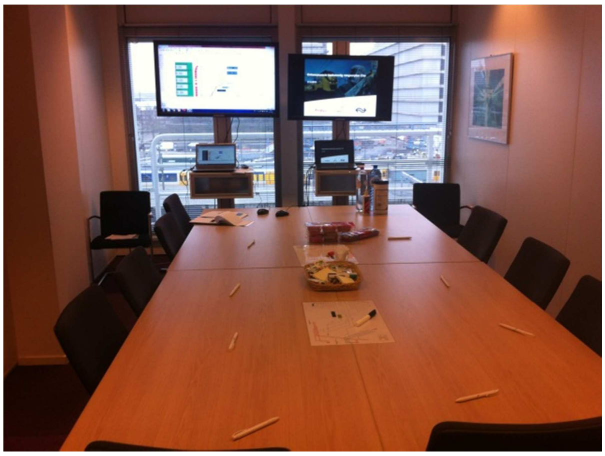
Figure 3: Setting Design Workshop

On the left screen the animation runs for the visualization of system's behaviour and some performance indicators are added for the visualization of system's performance on actors' KPIs. On the right screen a presentation was passed through with the visualization of the performance of the system on more KPIs by graphs and tables.

Within the 3-hour workshop there has been started with the discussion on the performance and behaviour of the system of Ctw in the current situation and future situation with the TC in operation. Subsequently the discussion on the design for a shunting plan including measures to improve the logistic process on Ctw have been discussed.

Upfront the workshop actors were asked to fill out the pre-test and after the workshop ended the post-test. The observer from the reference case Wgm joined the workshop and is consulted a few days after the workshop to reflect on the influence of multiple perspectives within the simulation. The post-survey was filled out by the participants a few weeks after, to identify the influence of multiple perspectives moreover.

## 4. RESULTS

Subsequently the results on the pre-test and post-test, the survey and the observations will be discussed as described in section 3.3.

### 4.1. Enhancement of SU

The pre-test and post-test have been filled out by 7 participants. In table 1 the results for both tests are given. During the post-test the participants were also asked about their perceived improvement of their SU. These results are shown in the rightmost column.

Table 1: Results Pre-test and Post-test on level of SU (SR = Social Relation)

| | Results | | | |
|---|---|---|---|---|
| Question | Pre-test* | Post-test* | Wilcoxon test (p-value) | Perceived improve-ment** |
| Content 1 | 4.71 | 5.43 | 0.01 | 5.57 |
| Content 2 | 3.00 | 5.00 | 0.01 | 5.43 |
| SR 3 | 3.43 | 5.29 | 0.01 | 5.43 |
| SR 4 | 3.29 | 5.00 | 0.01 | 5.71 |
| Process 5 | 3.57 | 4.89 | 0.03 | 5.14 |
| Process 6 | 3.43 | 4.43 | 0.03 | 5.00 |
| Average scores of participants. N = 7<br>* range 1-6<br>** range 1-7 | | | | |

Table 1 shows that the average scores on questions in the post-test are significantly higher than in the pre-test. We used a non-parametric test to account for our small sample size. Moreover the average scores on the perceived improvement are in the range 5.00 – 5.71 out of 7. Our interpretation of these results is that the participants experienced an increased level of SU after the workshop.

### 4.2. Influence of multi-perspective visualization on enhanced SU

Among the participants of the design workshop an additional survey was held to identify the effect of the multi-perspective visualization on the enhancement of SU.

Table 2: Perceived influence of Multi-Perspective Visualization on SU

| Aspect of SU | Average score on propositions* |
|---|---|
| Content | 5.92 |
| Process | 5.42 |
| Social Relation | 5.04 |
| Overall | 5.75 |
| *** (1 = totally disagree, 4 = neutral, 7 = totally agree)** | |

In table 2 the average scores for each aspect of SU as defined by Mulder (1999) are shown. These scores were calculated from the individual scores on the positive and negative propositions as discussed in section 3.3 (Zaalen 2013, p. 70).

It can be concluded the average scores for the aspects of SU are all higher than 4. This indicates that for each aspect the participants agreed that the multi-perspective visualization contributed to a higher SU.

From the participants' response we derive that the addition of the multiple perspectives in the visualization has a medium to large influence on the level of SU (5.75 out of 7). The results of the post survey show little variation in the scores of the different aspects, ranging from 5.04 to 5.92. Therefore the influence of multi-perspective visualization of the simulation within an SBD process is concluded to be substantial as indicated by the participants of the workshop.

### 4.3. Observed effect of multiple perspectives

The project manager of the reference case Wgm joined the workshop to observe whether or not the addition of multiple perspectives created a higher level of SU. The project manager was consulted after the design workshop and was questioned during a 2-hour interview on the behaviour of actors and the influence of the multi-perspective visualizations. The following conclusions were drawn from the interview:

*Great influence on the level of SU*: through the multi-perspective visualization actors got a very good insight in the behaviour and performance of the system, not just for their own interest but for the entire environment. During the discussion on the current performance and behaviour of the system just a few questions arose and all actors indicated to understand the system, its behaviour, performance and the problem to solve.

*Structures discussions*: Discussions on alternatives were primary based on the visualizations of KPIs. During the discussions the participants often referred to the numbers visualized for the KPIs, comparing them and using this in their argumentation. The observer indicated that actors were convinced more easily by the reference to the visualizations. As she said: 'the participants had a lot of handles to use in their argumentation'. As expected, certain dilemmas arose during the workshop, but they were solved by the insights that the visualizations gave on actors KPIs. In the discussions each actor structured his line of argumentation on the visualizations of the KPIs, pointing out the positive and negative effects for his own values, but acknowledging negative effects for other actors if present. As a final step in their argumentation the actors summarised the effects as perceived by themselves, resulting in their final opinion.

*Leads to relevant discussions*: The discussions were very substantive and only addressed those aspects which were useful to discuss. While discussing the alternatives, actors encountered other actors' positions in an early stage. Doing so, they made quick progress in the discussion because they could see the impact of the alternatives on other actors' KPIs: if the impact of a particular alternative was very negative to others, actors already took this into account in their argumentation and opinion about the specific alternative. This led to just very useful discussions on the details of alternatives which were acceptable for all actors.

*Every type of discussion needs a specific type of visualization*: During the design workshop the discussions could be split up into 2 different types; 1. on the current behaviour and performance of the system and identification of the problem and 2. on the alternative solutions. For the first type of discussion the animation of the system of Ctw was much most important. Actors got a very good insight in the behaviour of the system and understood what the problem was. During the discussion on alternatives actors referred a lot to the visualization of KPIs. The animation was not as important anymore and participants even asked if the animation could not speed up a bit because they could not identify the effect of the alternative solution from the animation as shown.

Altogether, the observations led to the conclusion that the addition of multi-perspective visualization within an SBD process creates a more structured and efficient design process and enhances SU among participants.

### 4.4. Practical implications

Using multi-perspective visualizations in an SBD process lead to a one-off design session in which all actors came to a consensus on the alternative to implement. It gave rise to open discussions that enabled actors to identify the full effects of the alternatives. As a result the final decision to implement a particular alternative was supported by all actors.

Moreover, the design workshop that was organized gave the actors the insight that collaboration leads to better design results. The insight that actors received about other actors' values and interests and the added value of a collaborative design process created the intention for further collaboration.

However, organising a design workshop, in which all actors together discuss on a design for a particular system, is quite difficult. All actors have their own agenda and priorities, which makes it difficult to gather all critical actors within an SBD process simultaneously. These organizational problems concerning the presence of actors can be mitigated by for example video conferencing.

## 5. CONCLUSION AND DISCUSSION

The experiment on the enhancement of SU by the addition of multiple perspectives within an SBD process has shown that SU is enhanced through the addition of multi-perspective visualization. By the design workshop for a new shunting plan for the marshalling yard Cartesiusweg critical actors participated in a 3-hour workshop, in which an observer from a reference case was present to identify the influence of multi-perspective visualization. Moreover the participants were asked to fill out a pre-test and post-test to identify their perceived SU and a post survey to check whether or not the enhanced SU is caused by the addition of multi-perspective visualization. From the evaluation tools the conclusion is that by the addition of multiple perspectives the SU is enhanced significantly, with a substantial influence of the multi-perspective visualization. From observations it can be concluded that for the SU on the behaviour of the system the visualization by animation has the most impact. For the SU on the performance of the system, the focus is more on the visualization of actors' KPIs. Because actors have insight in the performance of the system on other actors' KPIs the discussion is already discussed for a greater part. Actors already assess others' reactions and take this into account during the discussion.

The case used for the research study is typified by the actor field, in which all actors are dedicated to the logistic process. Furthermore the location and type of railway section, the marshalling yard of Utrecht, are typical for the case study. For similar cases the effects of the addition of multi-perspective visualization are expected to be the same. Design projects focused on logistic processes on a railway network will require other type of visualizations and possibly another software tool to simulate, but the effect of adding more perspectives is expected to be the same. For SBD projects in general the approach with multi-perspective visualization is promising, certainly because the actor field will be more diverse. However, this will require another approach of the SBD process and other types of visualization. To introduce actors with the design project and involve them in a design workshop will take a lot more effort, but will certainly contribute to a higher level of SU and a better design result in the end.

The tool of Mulder has been used in order to measure the level of SU. This tool was not a thoroughly validated tool. Moreover this case study research consists of a single case. Therefore more case studies should be performed to strengthen the conclusions of this experiment. In the end it is concluded there is a substantial influence on the enhancement of SU by the addition of multiple perspectives, however the quantitative extent of this influence is not known yet. Further research on the quantitative extent of influence should be performed to identify to what extent the multiple perspectives contribute to a higher SU.

Finally, it is experienced that the key to success is the openness and willingness to cooperate of critical actors involved. The creation of SU is crucial in whatever design project and can be enhanced significantly by the method of SBD with multi-perspective visualization.

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