Improving effectiveness of simulation studies using building blocks

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Abstract
Even though discrete event simulation is seen as a powerful problem solving tool, day-to-day use is still neglected. We noticed that this is a result of (perceived) low effectiveness of simulation studies. As a solution to improve the effectiveness of simulation studies, we identified a possible improvement for simulation studies, *simulation building blocks*. In our first experiments using *simulation building blocks* to support simulation studies, we noticed improved effectiveness, although not every set of building blocks contributed to an improvement of the effectiveness. We blame the architecture used for the definition of the building blocks, for this lack of contribution. Based on these experiences, we identified requirements for a new and more generic architecture. We developed a new architecture consisting of *model building blocks* and *building block elements* of which we expect that building blocks that are constructed according to this architecture will lead to an improvement in the effectiveness of simulation studies. In this paper we sketch how we think this new architecture should be evaluated, using different case-studies, laboratory experiments and expert validations.

1 Introduction
In contrast to what was expected for a long time (Pegden et al 2001), discrete event simulation is not used on a day-to-day basis by decision makers, even for data-intensive decisions that require quantitative analysis. Simulation studies can be seen as a tool for problem solving (Sol, 1982; Bank 1998) where several simulation models are developed to represent a problem domain. The problem is analyzed using the outcome of the simulation model, possible solutions are defined and experiments are performed using the developed model(s) to evaluate these possibilities.

In this research we look at simulation studies which supporting decision making in problem domains that are characterized by the following topics:

- multi-actor environment, in which different actors have different perspectives and interests
- simulation studies that normally take a couple of months to a year, due to the complexity of the environment, the number of processes and the required detail
- simulation studies that have a repetitive character and are used several times in the decision making process, not one-shot-models

- repetitive parts often represented by resources like workers and infrastructure that needs to be changed in the study, but is used in different ways.

The simulation models resulting from such a studies often are large, touch the boundaries of simulation tools and include a lot of hard to understand coding, in best cases separated over different simulation parts, and important connections that are not clear.

In these projects two kinds of problems can be recognized: managerial problems and technical problems. The managerial problems are things like changes in the organization before the simulation study is finished and "language"-differences between the simulation expert and the domain expert. An examples of the technical problems is a lack of knowledge of the way the process within the problem domain works and as a result it is hard to model the process. Secondly provided insight to the domain expert will lead to new questions, which are impossible to answer using the developed models.

Many processes of decision making have a low effectiveness due to the mentioned problems while performing simulation studies. The following performance indicators are used to determine whether we succeeded in improving the effectiveness of decision making using simulation studies.

- Ability to answer new questions from problem owners, i.e. number of questions that could be answered adequately
- Time needed to perform the study, i.e. total time for conceptualization, development of model, verification and validation of the model and analysis of the outcome
- Effort required to translate conceptual models into a simulation model
- Ability of simulation novices[1] to perform the simulation study.

Within the software industry, a lot of emphasis is spent on object oriented and component based developing, instead of on procedural software. The reasons give for this change are: (Meyer, 1999)

- Reusability
- Maintainability
- Extendibility

Even though developing a software application is different from performing a simulation study, e.g. reduction, abstraction and experimentation, the starting point of this thesis research is object oriented and component based thinking with the goal to improve the effectiveness of a simulation study. We used a three phase research approach to achieve this goal:

- Phase 1 – Inductive phase to get practical ideas of how well object orientation and component based modeling works for performing simulation studies (section 1)
- Phase 2 – Define a theory of how to support decision making using simulation studies more effectively and test this new theory in one or more practice cases (section 2)

[1] We define a simulation novice as someone who has knowledge of a domain, but only limited knowledge of simulation. If it proves possible to train a domain expert to develop models that represent systems, the simulation studies gain effectiveness because there is no loss of knowledge in the communication process between domain expert and model developer

- Phase 3 – Evaluation of the defined and improved theory using a laboratory experiment and interviews among experts in the field of simulation studies (section 3)

Currently our research is in phase 2, but we will look forward to the outcome of this research in the fifth section.

2 Phase 1: Inductive phase

The way phase 1, the inductive phase was performed is shown in figure 1. An explanation of the methodology used is followed by a short review of the outcome of the inductive cases and the literature, and an outline of the research problem, research question and evaluation criteria is given.

2.1 Research approach phase 1

Low effectiveness of simulation studies is a problem found in practical simulation studies. The starting point of this research was the idea to use object oriented concepts like inheritance, aggregation and encapsulation to develop class libraries consisting of a set of classes to be used in (several) simulation studies. The effectiveness of the support in decision making will be compared to simulation models developed in traditional more common ways i.e. flow oriented. The goal of our first case studies was to provide insight into a “trial and error” way of working also called “inductive case research” (Sol, 1982).

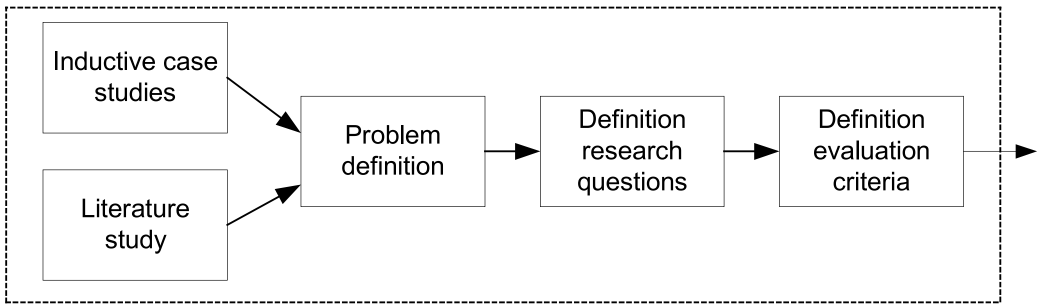

Figure 1: Inductive phase

A parallel literature study was performed focussing on the developments in the area of software development and simulation, see figure 1

Based on the outcome of the inductive cases and the literature study the problem definition for this research will be determined, including research questions and criteria to be able to identify whether the solution is working.

2.2 Inductive cases

We performed two inductive cases, to identify whether object oriented simulation helps in improving the effectiveness of support in decision making using of simulation studies. The first case dealt with automatic guided vehicles and the second with passenger movements at airports. (Verbraeck *et al.* 1998; Versteegt & Verbraeck 2001; Saanen 2001; Verbraeck & Valentin, 2001).

Both sets of simulation studies showed about the same kind of results with regards to the use of class objects. With positive outcomes for ease of model construction and ease of change for a simulation model, in this cases mainly for the physical infrastructure and understandability of the simulation model by the domain expert. Unfortunately negative experiences results were also identified. These were:

- Reuse of a set of building blocks over several studies is difficult, even in a specific domain
- Changing control systems in a simulation models is difficult
- The usability of the building blocks for people lacking experience with simulation was less then expected
- Developing building blocks at a relevant reduction and abstraction level is difficult

2.3 Outcome literature

Analogous to the development of component based software (Szyperski, 2001; Heineman and Council, 2001), simulation model builders are using components to construct their models. When constructing a model of a complex system that in reality consists of several components from different vendors, e.g. a part of a factory with a number of machines, it would be ideal to construct a simulation model of the factory using simulation components that have a one-to-one match with the machines on the factory floor (Sarjoughian & Cellier, 2001). In the vision of Fishwick (1998), it would be ideal if these components could be downloaded from the web-sites of the machine vendors and allowing them to be plugged into any simulation model. At the moment, however, this is barely possible due to a lack of "open" simulation environments. Fishwick believes it may take several years more before even part of this vision is realized. Even worse, we need to think about the architectures of these building blocks that would allow such advanced use. Fishwick (1998) and Pegden *et al.* (2001) have provided some first ideas for these interfaces and the functionality of the required components, but existing commercially available simulation tools do not as yet provide such components.
The research performed by Kasputis and Ng (2000) provides an example of possibilities for building blocks with current technologies have shown that is is possible to higher effectiveness in decision making by using a set of components taken from simulation models which they developed for the US Navy. However, their solution is not easy to generalize, because these components are fixed within one organization, and require the simulation software of the US Navy.

Current discrete event simulation software tools provide different kinds of components, each tool gives it a different name, some of them are "module", "atom", "object" and "shape". To avoid confusion with software component, will the term building blocks be used in this article. In the simulation tools, building blocks are applied on three different aggregation levels: domain independent building blocks, domain specific building blocks and user developed building blocks.

At the bottom level, we see generic, domain independent building blocks like a queue and a resource, actually wrapping the concepts of the simulation language in a user-friendly way. Each commercial available simulation package provides these concepts.

At the second level, building blocks are used as part of the simulation tool focussing on a special domain. Examples include transporters and conveyor belts within the simulation packages Arena and eM-Plant (www.arenasimulation.com; www.eM-Plant.de), PowerAndFree or Automatic Guided Vehicles in the simulation package Automod (www.brooksautomation.com) and MedModel of the simulation package Promodel.(www.promodel.com)

In addition, some tools offer the possibility for users to develop or extend building blocks according to their own, very specific, needs. These sets of building blocks can be developed by the vendor like for example Contact Center and Factory Analyzer libraries of Arena (www.arenasimulation.com) and the Harbour Systems of eM-Plant (www.eM-Plant.de). The user can also construct building blocks for a specific domain. The best simulation packages to use for this are the simulation tools Arena, eM-Plant and Extend (www.imaginethatinc.com) , thanks to the functionality that these tools offer to building block developers.

2.4 Research problem, questions and evaluation criteria

The inductive cases showed only a limited improvement in supporting decision making object oriented modeling approach. The object oriented modeling approach reduced the model construction time and improved the ability to change constructed models, so long the model specifications fit exactly in the range of the set of building blocks that the building block developer envisioned when creating the library. The same observations can be drawn from use of the sets of building blocks developed by simulation vendors. There are two major reasons why simulation studies do not show the improved effectiveness in supporting decision making like we expect:

1. The *architecture* of the building blocks, i.e. the format that lays underneath the principle of building blocks
2. The *process* of designing building blocks, including choices for abstraction and reduction levels.

Based on the outcome of the inductive cases and our literature study, we identified the following research questions:

1. What *architecture* for simulation building blocks provides improvement of effectiveness of simulation studies in decision making process?
   - Requirements?
   - Technical format?
2. Which *process* should we use to develop simulation building blocks?

3 Phase 2: Definition phase

3.1 Research approach phase 2

The definition phase starts with the outcome of the first phase, in which the research questions are defined. The phase starts with answering the questions given in section 2.4 as well as possible, by defining requirements for the architecture, defining the architecture and defining the process for describing the process of designing building blocks.

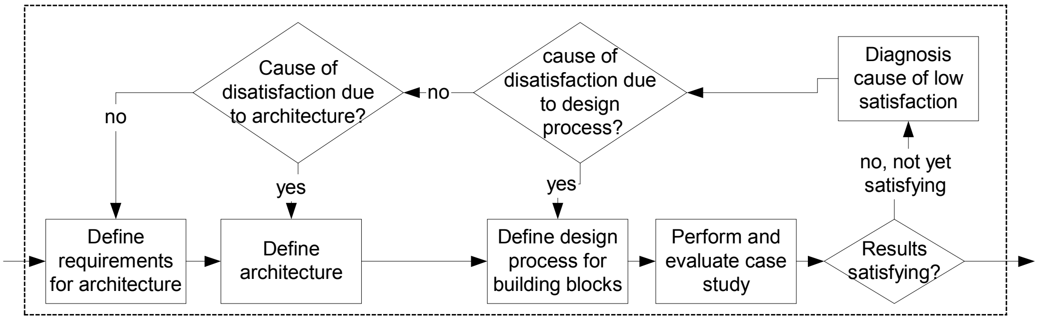

Figure 2: Research approach phase 2

The next task of the definition phase is a case study, described in detail below, see figure 2. Once the case study is evaluated the next research phase can start if the results are satisfactory. Redefinition of the architecture and the design process will be performed, once the results of the case study with regards to supporting decision making are not satisfactory

Performing a case study

The problem dealt with in this study is highly practical. The effectiveness of the support for decision making provided by simulation studies, can only be determined using in real decision making processes, because the main result of an effective simulation study is a decision how to continue in the modeled situation.

In the first part of the definition phase, we defined what we expect building blocks will look like and how these should be designed. There we implement these ideas in practical case studies. A new kind of building block was used, in a complex environment. Where the problem domain of the case study showed a need for several simulation studies, this allowed us to test the reusability of the set of building blocks We then evaluated the effectiveness of the support in the decision making process by interviewing the involved parties. The interviews should at least show that the performed simulation studies supported decision making and that the simulation related questions that evolved during the study could be answered by the outcome of the studies, to be able to speak about satisfying use of building blocks at least.

Evaluation case studies

It is likely that the results of initial case studies will show a large gap between ideas regarding the process and the building blocks and the actual result and that even after many case studies differences will exist. However, at some stage the difference between the ideas and the results of the case will be so minimal, that the definition phase can be ended.

The conclusion “enough case studies done” can be drawn once the resulting evaluation of the studies is satisfactory. If the comments are detailed this shows that the involved stakeholders were satisfied with the outcome of the simulation studies and could use this in their decision making process. The detailed evaluation consists of two parts. A part explained by the building block developers involved that give their opinion to the technical (software engineering) part of building blocks and a second part regarding the model builder and the domain expert that explain whether they feel comforted whether possible future studies can be performed as well using the building blocks. These evaluation interviews will be used to answer the questions “Are improvements possible” and if so, were can these improvements be gained. If the evaluation shows that the openness of the building blocks, the extendibility of the set and the ability to solve new problems show positive evaluation, one can assume that the design approach to reach the set of building blocks is fine. If for example functionalities are missing, then the question should be asked: “Was the analysis of the domain well-done?” If so, the problem very likely has to do with extendibility, if not the design approach for evaluation of the domain should be reconsidered.

3.2 Defined requirements

The requirements for simulation building block libraries come from two different sources. The first set of requirements is mainly based on literature and is aimed at support to improve the effectiveness of simulation studies. The second set of requirements follows from experiences with the architecture of available simulation libraries, which we tested in several projects More about the requirements and the architecture can be found in Valentin and Verbraeck (2002).

The first set of requirements for the architecture of simulation building blocks is based on an analysis that looks at the possible contribution of building blocks to the improvement of the effectiveness of a simulation study. The following requirements were obtained regarding models that are constructed using the set of building blocks

- *REQ 1: Support easy model development*
- *REQ 2: Resulting models should be understandable for problem owner*
- *REQ 3: Resulting models should be ready for Verification Validation & Accreditation (VV&A)*
- *REQ 4: Easy adaptation of developed models*

Requirements regarding the building blocks are:

- *REQ 5: Usable within several simulation studies*
- *REQ 6: Applicable in current simulation tools*
- *REQ 7: Building blocks should be maintainable and extendable*
- *REQ 8: Domain specific blocks with a manageable size*
- *REQ 9: Not closed, but also not completely open*
- *REQ 10: Flow of objects and method calls*

3.3 Defined architecture for building blocks

We define a building block as a self-contained (nearly-independent), interoperable (independent of underlying technology), reusable and replaceable unit, encapsulating its internal structure and providing useful services or functionality to its environment through precisely defined interfaces. (Verbraeck et al, 2000). This leaves us with three key issues for the architecture:

- providing functionalities
- interfacing with other building blocks
- representation to the environment (user)

Providing functionalities

When we look at the functionalities of our inductive cases we notice they all have several functionalities. E.G.: the vehicles can drive, move a load and talk to a control system and the passengers can queue, shop and spend time. In our experiments we often want to change one of these functionalities. The literature provides us with three mechanisms to do this:

1) Develop one huge building block that includes everything
2) Develop an inheritance structure with all kinds of abstract classes
3) Use aggregation

Option 1 results in a building block that is not maintainable due to all the functionalities and hard to use due to the required user input.
Option 2 will result to functionalities that need to be modeled several times, which means double work.

So we chose for option 3, the use of aggregation. To do so, we determined two levels of building blocks. We call the first level *model building blocks* and the second level *building block elements* (BBE). Model building blocks will be constructed using different building block elements that each represent one functionality. Building block elements can never be used directly in a simulation model, but will always be part of a model building block. Different kinds of model building blocks can be designed and used in the simulation model, by constructing model building blocks using different building block elements. Figure 3 shows an example of two different model building blocks (XYZ and XYZ'), using different building block elements (A-1; B-1; C-1 and C-2).

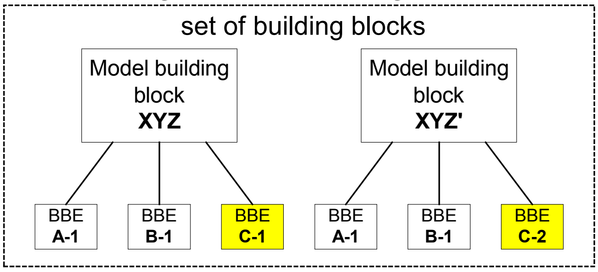

Figure 3: Example of a set of building blocks

Interfacing with other building blocks

We need clear interfacing combined with "hiding" of information. The open / closed issue is mostly a problem because of accessing information or methods a user is not allowed to use or change. This problem is solved, by defining specific *interfaces* around a building block. Secondly, information within the building block should be split up in *private and public* information.

Representation to the decision maker

A set of model building blocks, consisting of a larger set of building block elements should provide a tool that can be used to support simulation studies within a certain problem domain. However, within each problem domain one can always identify one or more studies that cannot be solved in an effective way using the proposed set. As a result we limited ourselves not only to one problem domain, but within that domain to a set of issues we could solve.
To improve the use of the set of model building blocks, we took the following three topics into account:

- Model building blocks are representations of items the decision maker identifies within a problem domain
- The user interface – both the descriptions in the user dialogs to set input figures and the animation provided – contains the terminology used in the problem domain by decision makers
- Development of new model building blocks using (new) building block elements will lead to support in decisions making for problems not noticed in studies performed before

Summary of the architecture

In summary, a set of building blocks consists of model building blocks that are constructed of building block elements. These building block elements communicate using standardized interfacing, using formal entries for message and entity passing. The building blocks are combined together in a user interface that shows domain specificity by using the right terminology and visualization like the decision maker expects. More details about the architecture can be found in Valentin and Verbraeck (2002)

3.4 Process of designing building blocks

Most sets of building blocks are focussing at one problem in a domain, without taking into account alternative problems the decision makers face. The main part of the design process is to start from the awareness of the problems the decision maker is struggling.

We suggest a four phase approach to design and implement the set of building blocks:

1) Conceptualization problem domain
= Perform the conceptualization of several possible studies and find out what kind of support the decision maker expects in these phases

2) Analyze of domain as seen by domain expert
= Develop an object model and a process overview of the problem domain, from the stand point of the domain expert/decision maker; added with some typical simulation required objects like statistics and generators

3) Translate to building blocks
= Translate the outcome of phase one and two to model building blocks and building block elements

4) Implementation of building blocks
= Implementation of the designed building blocks in the selected tool

3.5 Performed case studies

The first case performed was a luggage system at airports. The building blocks have led to support in decision making at airports Athens, Frankfurt, Schiphol and Singapore. Among the observations, the two main ones were fast model development thanks to a link with AutoCAD and problems with verification and validation of the set of building blocks by model builders. This was a result of the misunderstanding of the concept used for control of process and the lack of interaction with the future model builders. This case study lead to a change in the design process.

The second case was the modeling of Supply Chains, mainly the information exchange. We succeeded in providing a flexible and understandable way of controlling, thanks to the concept of model building block and building block elements. Unfortunately exchange of information between building blocks was a problem due to the used way of interaction.

The third case performed was the modeling of Business Processes in banking and government environments. The model seem to show the required flexibility and understandability, but the application models are not yet performed, so decision makers did not try to use the outcome of the simulation studies yet.

4 Phase 3: Evaluation phase

A final evaluation should be performed, based on the outcome of previous phase. Currently phase 2 is not yet finished, so the evaluation phase cannot be started yet. As a result, in this section we can only describe the research and cannot provide results.

4.1 Research approach phase 3

The last phase of this research consists of two different ways of evaluation mechanisms. These are laboratory experiments and expert evaluation and will be performed in parallel.

<u>Laboratory experiment</u>

The disadvantages of using case studies is that you cannot compare two or more different ways of performing the same simulation study. Whether or not the designed architecture for building blocks improves the effectiveness, can only be determined when two or more different architectures are used to perform the same simulation study. This is unlikely to be achieved in practice, so a laboratory experiment should be designed, in which the same simulation study is performed by different persons, while other parameters are fixed. These parameters are:

- experience of the model developers in the problem situation
- modeling knowledge and experience of the decision maker
- availability of data to be used to design, fill and evaluate the simulation models
- organizational structure of the system that is modeled

It is planned to perform the laboratory experiment, by defining a problem within a problem domain for which several sets of building blocks are available, each of them constructed with a different architecture. The problem description, including a first set of data can be handed over to different groups of simulation experts, who perform the study using a set of building blocks. The simulation experts can be scored on available knowledge, as can the sets of building blocks on their quality. The scoring of the simulation experts can be done based on an interview regarding their experience, the scoring of the sets of building blocks can be done by showing them to a team of simulation and domain experts that do not participate in the experiments.

The better the simulation experts, the more generic the set of building blocks should be. The outcome of the simulation studies can be scored on the issues mentioned at the beginning of this section. If the good-simulation experts score lower then the less-experienced simulation experts that used the building blocks according to my architecture, this should prove that the building blocks according to the architecture improve effectiveness. This is done to make sure that the difference in outcome is maximized. As an example, if the best simulation experts do not succeed in developing a model with a set of building blocks, in the same amount of time, or with a lower quality then the less-skilled simulation experts, it proves the effectiveness of the architecture.

Within the curriculum at our faculty, our students have several degrees of simulation experience, so we can use them to perform the laboratory simulation study as well. We suggest using Business Process Modeling, as the problem domain, partly because our students have some knowledge in that field and partly because several sets of building blocks are available within the same simulation language. The sets of building blocks to be used are the *Basic Process and Advanced Process* (Generic building blocks), *BP$im* (model building blocks developed by Rockwell Software), *TaakActor* (set of building blocks designed based on vanEijk, 1996) and the set of model building blocks developed for the project in international banking (Ayad and Sol, 2002).

Expert validation

As mentioned in the second section of this paper, in the past years several researchers have defined extensions to object orientation as an architecture for building blocks to construct simulation models. We have found that they have succeeded in developing the building blocks according to their own architecture, but we have noticed that they did not increase effectiveness, different then a handy tool for fast and easy simulation model construction. The experts that were involved in these studies could be useful sources of information and could be asked to validate our architecture. We have identified three kinds of experts:

- Experts from within the research world
- Experts from simulation companies, developers of commercial libraries
- Experts that use commercial simulation libraries

5 Expectations coming research period

So far, the case studies have shown that our ideas regarding the architecture and the design process are in the right direction, however, before we can be sure, some steps still need to be taken. The most important two are performing realistic simulation studies for the Business Process Modeling-processes and the Supply Chains and performing the complete evaluation interviews. At this moment, we do not have any reason to believe that we will not succeed in performing the studies with satisfactory outcome.

As a result the coming year will be spent finishing the case studies, performing the laboratory experiments and finally validating the requirements, architecture and design process using experts drawn from industry and academics.

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Biography

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