The technical-business aspects of two mid-sized manufacturing companies implementing a joint simulation model

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9.1 Introduction

Companies are increasingly developing their business-to-business (B2B) activities to offer more exciting products to end users and customers. However, because B2B business-model decisions are generally made without input from end users, these companies often do not achieve their sustainable business objectives. Simulation offers an opportunity to increase customer value at different phases of the product lifecycle (Ripley, 2009; Tao *et al.*, 2019). However, little research has been done on the technical-business aspects of implementing simulation in a B2B framework. Nonetheless, real-time simulation methods can tightly integrate end users and customers with B2B activity. In addition, many conventional simulation studies ignore the physics of the real world, which limits the possible technical-business advantages of simulation technologies. Introducing real-time simulation can eliminate this lack of real-world physics perspective.

Integrated with a modern simulator system, real-time simulation enables end users and customers to directly participate in the development and testing of products. If two manufacturing companies that are providing complementary equipment for a particular industry segment work together to develop a B2B joint simulation model, their end users and customers can be engaged to help select components or sub-components to design and test forthcoming products that provide better customer value. Using physics-based real-time simulation makes it possible for the end users and customers to experience the dynamic behaviors of the products represented by the joint simulation model. From a preset range of values, they can set the required component parameters to guide the design of optimal, accurate, scalable, and efficient products. In this way, real-time joint simulation efforts can contribute to the B2B activities of both participating manufacturing companies.

One identified industry need is to better understand the technical-business aspects of implementing simulation in mid-sized manufacturing companies.

Considering this need, this chapter focuses on a case example where real-time simulation models from two different Finnish companies are integrated to increase customer value with respect to B2B activity. Objectives include increasing the participation of the end users and customers, examining the feasibility of using parameterized simulation models, and exploring the technical and business aspects of the joint simulation effort. The case example involves the real-time simulation models of forestry tractor and harvester crane systems.

The chapter is structured as follows. The following section reviews previous research on the topic. The third section (Section 9.3) defines an architecture for building the joint simulation model. In addition, it determines how the combined model can be constructed based on user needs. The case example, combining the simulation models of the Valtra N-series tractor and the Kesla 6H-series harvester crane systems, is described and discussed in the fourth section (Section 9.4). The challenges experienced from both the technical and business points of view are reviewed. The section also proposes possible solutions (lesson learned). Conclusions are presented in the final paragraphs.

9.2 Related research

B2B activities would be more successful if end users had more input into product development. Customer value should be a key aspect of initiatives to establish customers and end users as stakeholders in B2B activities (Carmona-Lavado *et al.*, 2020; Lesmono *et al.*, 2020). To achieve and sustain a competitive advantage, customer value in product development must be improved (Anderson *et al.*, 2006; Zhang *et al.*, 2013). Moreover, there should be more participation in product development by end users and customers to better define the value of B2B activities through innovative ideas, skills, education, experience, and feedback (Aschehoug *et al.*, 2019; Orcik *et al.*, 2013). Parameterizing products in this way can increase collaboration between users and manufacturers, profitability, and product quality (Orcik *et al.*, 2013). In practice, the implementation of simulation technologies makes it possible to introduce the needs and choices of end users and customers in product development activities (Karlberg, 2013; Tao *et al.*, 2019).

To develop customer-oriented products, Boman *et al.* also suggested including users in product development via simulation (Boman *et al.*, 1998). Simulation use has been proven to be an efficient way to optimize the product development process, and it is widely used in industry (Mahesh, 2013; Oden, 2006). However, end users and customers can only experience the working cycles of already prepared simulation models. They cannot directly design and test new products (Tao *et al.*, 2019). To capture innovative ideas, users should be able to develop and test a new product simulation model while varying and selecting component parameters from a catalog according to application and needs (Goury, 2018; Mohammadi, 2019; Schmit, 2016). However, end user and customer choices are limited by the traditional use of simulation. This is because these simulation methods may not replicate the physics of actual products, or they do not allow a broad selection range of required parameters.

However, a multibody-based real-time simulation model, with its surrounding environment, gives end users and customers the opportunity to experience real-world operations. These real-time simulation models are physics-based models that include solutions to the equations of motion. The experiences and customer feelings offered by these simulations can be beneficial in the product development phase of B2B activities. Real-time simulation had been employed in multibody systems in various applications such as aviation (DuVal, 2001) and automotive (Dede, 2014; Tavernini, 2009). The hours of work needed to develop a model without any guarantee of achieving useful results is the biggest impediment to extending the use of real-time simulation (Quesada, 2016).

Efforts have also been made to develop customizable/generic real-time simulation models that are simple, quickly adapted, and modifiable by end users and customers (Mohammadi, 2019). For instance, Kaikko developed a simulation model to help find electric drive solutions for industrial vehicles exploring technical aspects of real-time simulation (Kaikko, 2015). Steele also studied a generic model, applicable to several systems, by focusing on the simulation information (Steele, 2002). From a business point of view, reducing build-up/manufacturing time is desirable. Therefore, a number of researchers have worked on improving the efficiency of the generic models to decrease manufacturing times in various areas such as logistics manufacturing (Wy, 2011) and drivetrain modeling (Zhao, 2013).

The technical-business aspects of a B2B joint simulation using customizable/generic models through real-time simulation have not yet been discussed. To fill this gap, this study provides a roadmap and details the technical-business aspects of building the customizable/generic product of a B2B joint venture through real-time simulation. It could help to establish a balance between the needs of different partners in a B2B activity to achieve better success.

9.3 Methodology: assembling the joint simulation models

9.3.1 Developing customer-oriented B2B products

Two reasons to use joint real-time simulation in product development are to minimize the need for physical prototype testing and to better involve users in the development process. Adding the user input increases the likelihood of manufacturing products that are customer-oriented (Karlberg, 2013; Xu & Li, 2013). Traditionally, B2B product development has relied on the use of digital tools, such as design software, by the development team without much input from users. In fact, there is typically no clear connection between the digital tools and the target users.

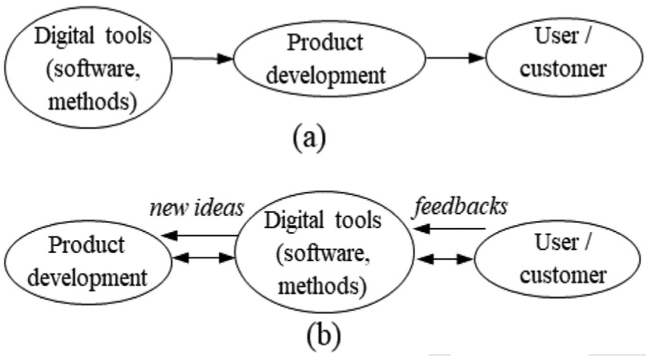

Figure 9.1 The traditional and proposed product development approaches in a B2B venture: (a) traditional and (b) proposed joint real-time-simulation-based product development.

Figure 9.1(a) illustrates the lack of user feedback typical for this traditional process path. The new product development concept explored in this study introduces a direct connection between the users and product development. This connection can be accomplished by using the digital tools as the bridge between product development and the users by including user experience in the model (see Figure 9.1(b)).

9.3.2 Preparation of B2B parameterized real-time joint simulation model

Users can participate early on in the product development process by helping to parameterize product simulation models to make them adaptable. As development progresses, they can vary and select component parameters, from a range of allowed values, that best meet their application and needs and then run simulations to test the resulting product behaviors. The product that results from this user-based product development approach should provide significantly improved customer value.

This parameterization approach can work even better and provide even more customer value when applied to a B2B joint simulation model that has been developed by two manufacturing companies supplying complementary equipment for a particular industry. For an industrial vehicle, there can be choices related to tire type and size, hydraulic forces, engine output, tractor parts, forestry machine parts, excavator, forklift, etc. Users can readily select their intended types and construct the model. Consequently, based on parameterization concept, an industrial vehicle can possess different assemblies with different functionalities. Real-time simulation methods can demonstrate these various combinations of machines in the real world. End users and customers, in turn, can decide which combination best fits the requirements of the job.

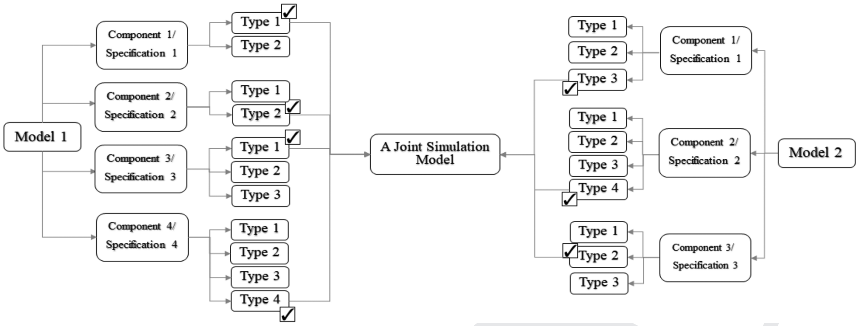

Figure 9.2 Assembling two models, each with various component/specification options, to construct a joint simulation model – the check marks in the figure show which types were selected for this particular simulation.

Figure 9.3 Parameterization procedure.

9.3.3 Combining parameterized models and the optimized model

Figure 9.2 demonstrates how a joint simulation model can be constructed by combining two separate real-time simulation models. Each model can comprise a number of different component types or specifications. Varying these sub-model parameters makes it possible to extract an optimum configuration that is fully customer-oriented.

Determining optimum components and specifications is important. Many scholars have been working to define optimum models and methods via simulation (Alfieri *et al.*, 2015). A well-executed simulation model optimization makes it possible to find the appropriate balance between technical and economic issues. Simulation optimization helps a manufacturer produce efficient products with less effort, which consequently reduces the cost of manufacturing (Fleischer & Krauße, 2013; Fu *et al.*, 2005).

A user-friendly interface can be designed to help users select their intended product configuration. Using a script, the selected configuration can then be implemented in the real-time simulation software. In fact, the written script acts as a bridge between the user interface and the real-time software. Figure 9.3 illustrates the concept of parameter implementation in real-time simulation software.

For better user interaction, visuals or Excel sheets can be used to provide options to end users and customers to select among the different models, components, and sub-components. This can be done via an advanced programming interface

User Interface		
Parameter to change		
Crane	**Length of the boom (m)**	2.35
Hydraulic part	**Nominal flow rate [l/min]**	170
Trailers	**Number of trailers**	2

Figure 9.4 A user interface constructed in Excel – users can easily select their intended parameters/specifications.

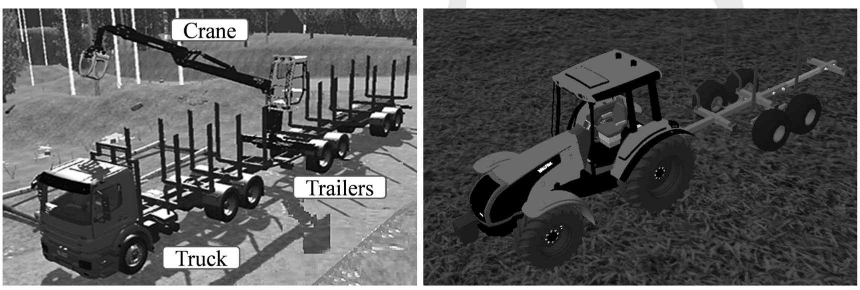

Figure 9.5 (a) The harvester crane system showing the crane mounted on the truck trailer, (b) the tractor with its trailer.

Figure 9.4 shows an example of a user interface constructed in Excel. As mentioned earlier, users can simply select their intended parameter/specification and implement it in the simulation model.

9.4 Joint simulation of industrial mobile machines

This chapter introduces the joint simulation model developed by combining the models for a forestry tractor system and a harvester crane system manufactured by two different case companies. Three parties collaborated in its development: the forest technology company, the tractor manufacturer, and a Finnish simulation technology company. The tractor system is based on the Valtra N tractor. The harvester crane system is based on the Kesla 6H. Figure 9.5(a) shows the harvester crane system. It comprises a truck, the crane, and a trailer. Figure 9.5(b) shows tractor and tractor trailer system.

The joint simulation involves the modeling of the systems, components, and hydraulic circuits of the two different product systems. Simulation software, developed by the Finnish simulation technology company, was used to construct the real-time joint simulation model. In the software, the equations of motion for the simulation models were constructed based on the semi-recursive method (Slaats, 1991) and were solved using the Runge–Kutta time integration scheme (Yang, 2015). The hydraulic circuit systems were modeled using lumped fluid theory (Watton, 1989).

9.4.1 Technical-business challenges of joint simulation/joint simulation challenges

This section details the technical-business challenges of the joint simulation of the tractor and crane models. The primary technical challenges were:

- choosing the appropriate parameters from the joint simulation models to be provided for user selection
- establishing a feasible range of parameters from which the end users and customers can request changes
- testing joint-model stability and joint simulation models over the range of parameters
- developing a new optimum simulation model out of the tractor and the crane models
- carrying out the user selection and testing of the optimum simulation model.

According to Jääskeläinen (2017), varying factors motivate different actors toward joint product development collaboration. The common motivators included business success and cost savings. Good motivation, clear goals, and an understanding of the benefits of collaboration from all parties involved are necessary for successful joint simulation modeling.

Exercising the simulation models, the participating companies will learn more about issues that arise and how flexibly their solutions can fit together (e.g., the tractor and the trailer combination). For example, consider a simulation model with two parameterized specifications and three types for each of the specifications. There would be six different combinations for this simulation model. Users can assemble models by selecting different parameterized specifications. The issues found can help to develop better solutions and synergy between products. Also, these benefits can also lead to advantages for the customer (better products), which can lead to more business benefit.

There may be challenges involved in implementing joint modeling and achieving business benefit. A lack of resources is the first issue usually faced. To build the models, companies need to bring on the requisite modeling expertise. Fitting together two different simulation models can be difficult. Bringing on these resources to get the job accomplished is an investment. Furthermore, support is needed from decision-makers to get the project budget and resourcing approved.

If an R&D manager needs support from a superior, they must present a cost-benefit analysis that can demonstrate the simulation efforts are going to result in a benefit to the business. Costs are easy to estimate but the future benefit from a business point-of-view is much harder to justify. The monetary value of benefits is often qualitative in nature (Boardman, 2010). Another challenge is that there are two or more companies involved, so they must both share a mutual understanding of the possible benefits offered and the effort needed.

Establishing an appropriate time-based strategy or schedule is always a challenge in any collaboration between multiple parties. In general, each party focuses mainly on its outcomes. For instance, each manufacturer will strive to improve its R&D (Nelson, 1986), its patent portfolio (Adams, 2001), and its process development (Mansfield, 1995). The priority objective for collaborating universities is scientific research. Interactions between manufacturing companies and universities lead to information exchange and the publication of joint research articles (Boardman, 2009).

Providing industry funds to accomplish an industry-academia project will increase collaboration, but it will also result in higher industry party expectations (Bozeman, 2001). Gulbrandsen and Smeby showed that researchers with industry grants are more effective at accomplishing, which is beneficial for both parties (Gulbrandsen & Smeby, 2005).

9.4.2 Real-time joint simulation solutions

9.4.2.1 Selection of optimal parameters

In the forestry industry, the truck and the trailer are designed with a specific number of optimal parameters. These parameters fall into different categories: hydraulic parameters, pulling forces, physical specifications (e.g., trailers' mass, center of mass), etc. Many parameters included in the truck and trailer simulation models are based on the needs of end users and customers. Concerned B2B companies further shortlist the chosen parameters by checking their feasibility in the individual simulation models and the real world. In the discussed case example, as shown in Table 9.1, optimal parameters are braking torque of the motor, number of rear tires, boom length, and cylinder diameter.

9.4.2.2 Optimal range of parameters

As Table 9.1 demonstrates, each parameter has maximum and minimum values/numbers. For instance, the maximum and minimum values for the boom length of the forestry vehicle model are 4.35 m and 5 m, respectively. If these parameters are not optimized appropriately, some of the joint models with parameterized specifications/optimized components can fail.

For example, consider a joint model with the maximum boom length and the minimum cylinder diameter. If the cylinder diameter is not adequate to

Table 9.1 Major parameterized components/specifications for the two case models – each has a certain number of values that users can select

The tractor		*The forestry vehicle*	
Braking torque for the motor (Nm)	5,000	Boom length (m)	4.35
	15,000		4.55
	25,000		5
	35,000	Cylinder diameter (mm)	1.105
	40,000		1.155
Number of the rear tires	2		1.195
	4		1.205

provide the required hydraulic force, the joint model will not operate properly. In any parameterized simulation model, there are a specific number of combinations, which have a probability of a failing, that are called "critical combinations". The critical combinations include a maximum value for one component/specification and a minimum value for another directly or indirectly related component/specification. Tractor and crane simulation models are tested at these maximum and minimum specification values.

9.4.2.3 Joint-model stability

Another challenge is to calculate the type and place of the constraint between the tractor and the trailer (see Figure 9.6). The joint type and its distance from the two models should be calculated precisely because it plays a crucial role in joint-model stability. The joint type should restrict undesirable degrees of freedom and simultaneously allow all intended movement directions. In this case, the modeling experts decided to use spherical joints to allow independent joint motions in all directions. A spherical joint drives a point from the trailer on its corresponding point from the tractor without constraining in its orientations.

In addition, to overcome any instability and dispose the distance calculation for point A, two frog legs are designed to increase the stability of the main-booms, the cabin, and the trailer. As Figure 9.7 demonstrates, the forces acting on the frog legs are supplied by two hydraulic cylinders that sit on the two sides of the frog legs.

9.4.2.4. Feasibilities of joint simulation combinations

Using the number of parameters from Table 9.1, a number of possible combinations of joint simulation models can be modeled. Critical joint simulation models are tested in this case study for feasibility and functionality. In this way, end users and customers can select the components/specifications of joint simulation in the provided range according to the application or needs of

Figure 9.6 The location of the connection spot (Point A) between two models.

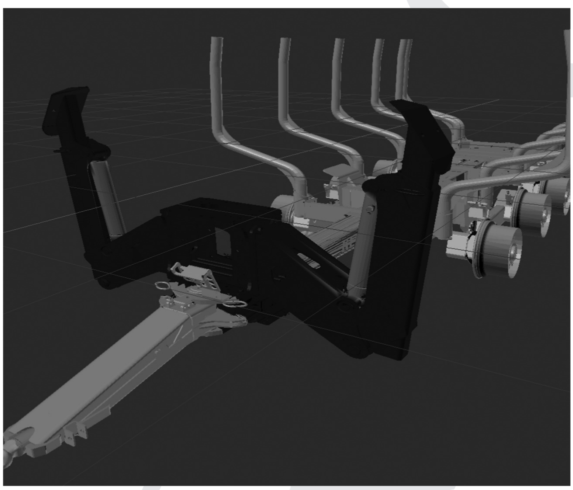

Figure 9.7 Frog-leg stabilizers to prevent the main-booms, the cabin, and the trailer from falling down to the right and to the left.

the B2B product and test the self-specified innovative product using different combinations. As mentioned earlier, among several parameterized combinations, there can also be infeasible parameterized simulation solutions (critical combinations). The B2B venture product development team must identify which solutions are not manufacturable or will not operate properly in the real world.

9.4.2.5 User selection of parameterized model/user designing and testing of simulation model

End users and customers can assemble different combinations of parameters in the joint simulation model and find the best optimal combination as per needs. Figure 9.8 schematically shows how these models can be joined. For the tractor model, e.g., a maximum motor braking torque = 15000 Nm, six tires, and four gears were selected. For the forestry vehicle, the boom length = 5 m, piston diameter = 125 mm, and cylinder length = 1,155 mm were selected.

These optimal types can be provided to the end users and customers on the simulator screen. Virtual reality and augmented reality tools can also be integrated with the simulator driven real-time simulations to tightly engage users. In the case of an infeasible simulation solution, end users and customers can report to the product development team. They have an opportunity to rectify their choices and specify a new feasible joint simulation model. Joint simulation efforts help to develop a closer communication between the end users and customers as well as product development team of a B2B venture.

9.4.3 Collaboration benefits and issues on the alliance

In the case study discussed, the joint model can be divided into two major sub-systems. The puller sub-system, the first, is related to driving the entire vehicle. The second is the trailer and cranes. In the joint simulation effort, the tractor system is the first sub-system and the harvester crane system is the second sub-system. Modeling for each sub-system is the responsibility of the corresponding experts. These subsystems can be interconnected to construct a joint simulation-model (see Figure 9.9).

Each sub-system can be designed and developed separately. All sub-systems will be assembled and prepared in the simulation model. Close interaction is needed between parties to define critical combinations. Depending on the objectives, the collaboration between parties may take on many forms including, for example, research contracts and monthly meetings. However, meetings between industrial and educational parties usually will occur informally, and their outcomes cannot be easily measurable (Hagedoorn *et al.*, 2000). Moreover, goals for each involved party can often differ. Some parties usually have more research-oriented scientific goals, while others have very clear-cut business-related objectives. This can lead to a situation where companies are not committed to the collaboration, even though the benefits are considerable (Kiron, 2017).

Another benefit of these collaboration situations is taking advantage of the experts and tools of the different parties involved and finding mutual interest areas. In the case described in this chapter, the university and the company partners had extensive open dialogue. Solving the technical modeling case was in the common interest of all collaborators, and the modeling was straightforward. The parties had a signed research agreement detailing how these results could

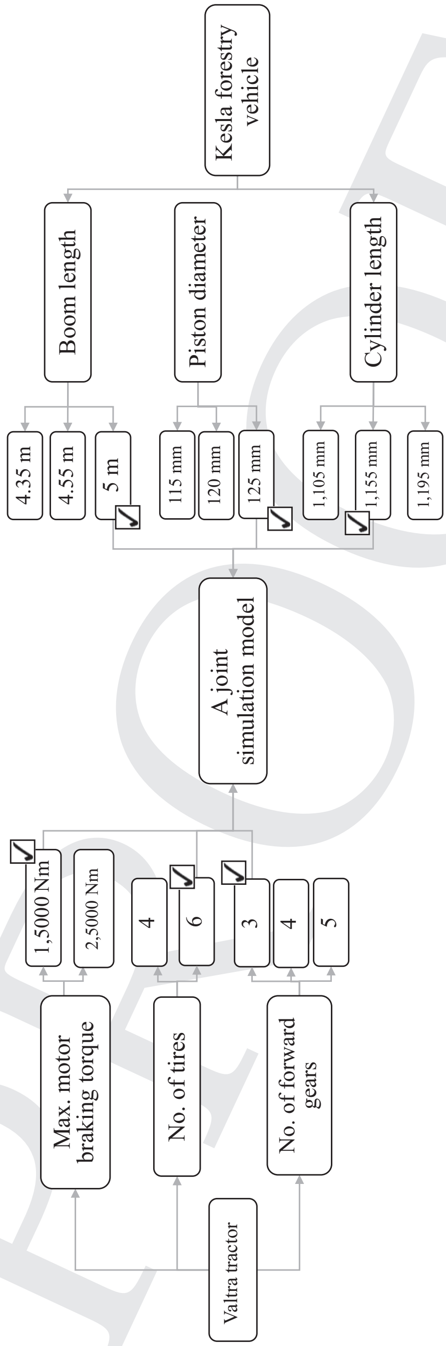

Figure 9.8 Schematic of the procedure on how two models can be assembled and joined together.

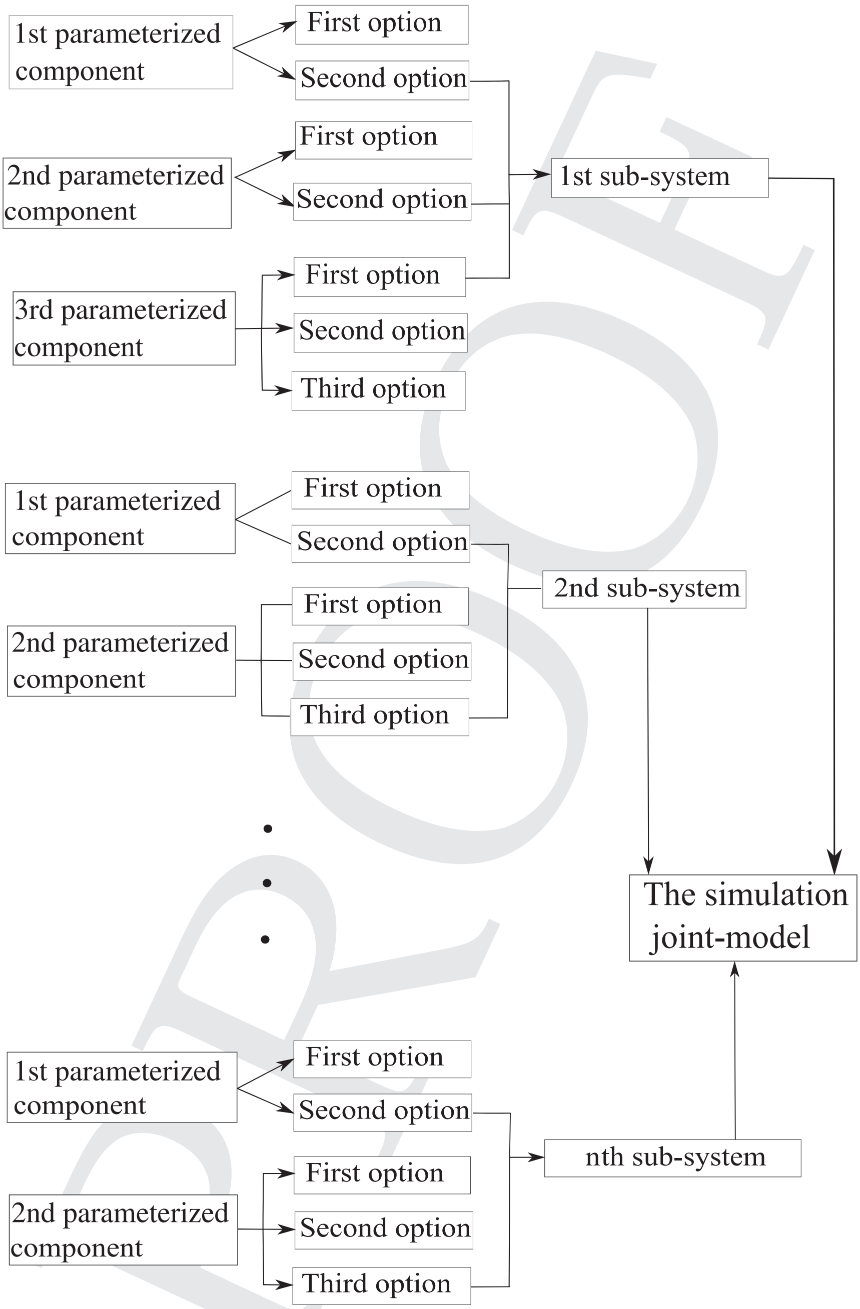

Figure 9.9 The process of constructing the joint simulation model comprising several sub-systems – sub-systems are specified using the parameterization technique.

be used, so there were no concerns about the intellectual properties of the possible new solutions. Having a written agreement on the utilization rights of the results is important, and this agreement should be made between the collaborating organizations before the collaboration begins.

In the described joint simulation case, the involved companies gained some understanding regarding each other's product. The joint simulation model offered a platform where these two companies could learn and discuss each other's products and joint venture issues. The communication bridges built during this collaboration will enable more thinking and discussion in the future with the potential of introducing new mutual business collaboration ideas.

When companies start to plan possible cooperation in simulation modeling, they should be aware of the typical challenges related to the management of such collaborations. Lack of resources (money, time, and simulation experts) are a common issue in these kinds of development projects. Additionally, a common vision of simulation modeling goals between the collaborating parties should be clear. The simulation teams should also have strong support from their management. When both parties have a clear understanding of the challenges, there is a better opportunity to actively plan for suitable means and resources to avoid common pitfalls.

To set common goals and avoid gaps in communication, collaborating teams should have common workshops, monthly meetings, discussion platforms, etc. This way, the sharing of information between collaborators will be open and timely. Understanding the motives and goals of each party helps to set the goals for the joint simulation effort. It is also easier to spot potential problems and react in a timely manner. Deeper collaborations can also help to identify possible long-term business opportunities and benefits (related to customer value and the utilization of the joint models for customer interaction).

9.5 Conclusions

In this paper a joint real-time simulation model of a combined tractor and harvester system was developed and the technical-business aspects of joint simulation were discussed. The model is composed of two different simulation models from two companies: a forestry company and a tractor manufacturer. The joint simulation model was designed to be flexible using parameterization. Table 9.2 summarizes the challenges faced and makes recommendations.

Collaboration between companies provides opportunities to take advantage of input from skillful experts in different fields. Furthermore, universities are able to convey updated knowledge and cutting-edge ideas to industries. However, projects established with teams comprised of people from different companies present a number of challenges that should be taken into consideration. Cooperation with customers can help designers to minimize the challenges and eliminate the barriers in different design and manufacturing phases.

Table 9.2 The challenges found and recommended solution procedures

Target	*Challenges*	*Possible solutions*
Technical aspects	- Developing an optimal joint simulation model out of two (or more) sub models that have been optimized for their environment. - Locating the connection point between the sub models - Employing a parameterization technique to offer different model combinations - Establishing the functionality of all joint-simulation model combinations	- Optimal sub-system models were developed with the collaboration of the experts from all parties. - The experts held frequent meetings to be made aware and to consider the overall situation to prevent problems and rework arising from the numerous critical combinations. - The critical combinations were tested and analyzed to ensure the functionality of all possible combinations. - Close interaction with customers was maintained to keep awareness of their needs throughout the work to develop customer-oriented models.
Business aspects	- Communicating fully and at the right time with all parties - Defining how the modeling leads to customer value - Determining modeling costs - Deciding how to use the new models in the future	- Common goals were established in workshops involving all parties. - Efforts were made to increase the common understanding of business benefits. - Support from management was solicited and obtained.

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