Universidade de Aveiro Departamento de Economia, Gestão e Engenharia Industrial
2010

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Desenvolvimento de software de simulação num contexto global de negócios

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Relatório de Projecto apresentado à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia e Gestão Industrial, realizado sob a orientação científica do Doutor Henrique Manuel Morais Diz, Professor Catedrático do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro.

"Technology changes everything"
(Hewlett-Packard advertisement)

o júri

presidente

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agradecimentos

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palavras-chave

Simulação, software, gestão da cadeia de abastecimento.

resumo

Com a globalização e o aumento de competitividade as empresas viram se forçadas a encontrar novas formas de optimização e de estar constantemente à acrescentar mais valor aos seus produtos.
Como resultado, existe uma mudança progressiva para uma perspectiva externa com ênfase na concepção e implementação de novas parcerias estratégicas, que são geralmente nomeadas com o título de gestão da cadeia de abastecimento.
No entanto, apesar do florescimento de várias soluções informáticas neste contexto, ainda há vários obstáculos evidentes a superar. Principalmente devido à maior complexidade dos problemas gerados numa rede logística onde existem conflitos resultantes de objectivos locais versus estratégias de integração.
A simulação que conta já com um vasto histórico em aplicações industriais poderá revelar-se numa importante mais-valia neste novo âmbito. Esta ferramenta é usada para efectuar análises, estudos, optimizar projectos e identificar novas oportunidades.
As empresas actualmente produzem numa rede complexa na maioria das vezes estão presentes em diferentes países, com múltiplas oportunidades de mercado. Normalmente existe a necessidade de produzirem componentes sofisticados que raramente são criados num único local.
Isso representa um desafio extra para a plena utilização das ferramentas de simulação. Este trabalho tenta validar a ideia de que há um potencial inexplorado no uso e desenvolvimento de software de simulação. Novas aplicações tecnológicas estão a ser formuladas que tiram partido destes novos parâmetros e dão resposta a um superior número de critérios de eficiência e de produtividade nas empresas. Em conjunto procuram dar uma resposta a estes problemas, bem como integrar plenamente e com sucesso as empresas em novas formas de negócio como a gestão cadeia de abastecimento.

keywords

Simulation, software, distributed, paralell, supply chain management.

abstract

The increased level of competitiveness in all industrial sectors, exacerbated in the last years by the globalization of the economies. This is pushing enterprises to find new ways to optimize their processes, and in particular to pursue new forms of collaboration and partnership with their direct logistics counterparts. As a result, at a company level there is a progressive shift towards an external perspective with the design and implementation of new management strategies, which are generally named with the term of supply chain management (SCM).
However, despite the flourish of several IT solutions in this context, there are still evident hurdles to overcome. Mainly due to the major complexity of the problems to be tackled in a logistics network and to the conflicts resulting from local objectives versus network strategies.
Simulation has now a solid background in manufacturing applications. This tool is used to perform analyses, studies, optimize designs and also identify problems.
Companies now produce in a complex environment and most of the times they are present in different countries with different market opportunities, manufacturing intricate products that are seldom created in a single location. This poses an extra challenge for the full use of simulation. This work tries to validate the idea that there is an untapped potential in simulation software. And new forms of distributes simulation techniques are growing to give an answer to these problems as well as fully integrate companies successfully into new ways of business like supply chain management.

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Abreviaturas

RBBE	BOSCH Tienen engineering research department
DS	Distributed simulation
DPS	Distributed parallel simulation
SCM	Supply chain management
HLA	High level architecture

1 Introduction

1.2 Thesis context

This document aims to describe work performed under the auspices of the (Estágio/Projecto/Dissertação), a subject currently included in the Bolonha Master (Engenharia e Gestão Industrial da Universidade de Aveiro). This work was carried out at Robert BOSCH Producktie N.V., located in Tienen, province of Flemish Brabant, Belgium. This company is a part of the BOSCH GROUP, in the Electronic Drives section of the automotive technology division, dedicated specifically to the production and manufacture of wiper blades. The work is designed to give an insight into the latest practices and uses of simulation technology, highlighting the role of simulation development in the current global business environment, as well as connecting possible future applications of simulation with the supply chain management concepts.

1.3 Thesis subject

Simulation is an indispensable tool for efficient product development at a growing number of companies. The time and cost benefits of engineering simulation are well-documented. This technology is used early in the product cycle to evaluate concepts, compare alternatives, identify problems and optimize designs. Predicting product performance and determining optimal solutions early in the design phase helps to avoid stage problems and to eliminate trial-and-error testing cycles that drive up costs. Simulation enables engineers to perform studies and compare alternatives, a process that would otherwise be impractical. Indeed, bottom-line savings is the one of the key benefits that motivates most companies to implement simulation, and is the most readily quantifiable in terms of return on investment calculations. These are among the powerful capabilities that enable companies to reduce costs, shorten time to market, improve quality and create innovative designs.

Thus, in the end, these benefits enhance overall revenue growth. With simulation, companies can develop innovative products that stand apart from others, make the status quo obsolete and create entirely new market opportunities. Brand value can be enhanced by increasing designs of new products or tackling projects that otherwise would not be attempted. Discussion of the business value of simulation is particularly relevant in today's world as manufacturers face the toughest economic climate in a lifetime. With their survival at skate, forward thinking companies recognize the need to invest in simulation now more than ever to withstand the current market turbulence and strengthen their long-term competitive position, brand value and profitability as a condition of improvement in the coming years.

According to [1], in order to attain a competitive edge, a business supply chain should be flexible, quick, dependable and cost efficient. These objectives are accomplished through high speed information and material flow with low overhead costs. Coordination and collaboration in different activities are essential to the success of supply chain standards. One of the most important aspects of the supply chain network is the need to minimize its cost by identifying optimal operating conditions. The use of simulation can play an important role in this and broaden its impact on this new global market. However, this is can be difficult due to the complexities involved in the dynamic interaction among multiple facilities and locations.

The development of simulation software has now reached a crucial stage, when communication and data security play an even more important role then the use of simulation alone. It is not the goal of this work to find solutions to all of these issues, but to recognize these problems on the verge of a new decade when computing capacity just seems to be growing can lead to better and more efficient simulation practice. This will ultimate bring value; the intelligent use of simulation can be a deciding factor in determining a company's long-term future, and will probably be a deciding factor in determining which companies survive the current economic chaos and emerge from recession stronger.

1.4 Thesis structure

The present report is structured in 6 chapters, the first one referring the reasons why it was created and the context, while stressing the importance of the current subject.

The following chapter aims to provide a theoretical framework about simulation, demonstrating the most common simulation techniques and their use, and also tries an approach on the main issues concerning simulation appliance.

The third chapter gives a brief introduction to BOSCH Producktie in Belgium with company facts and details about the main product range line.

The fourth chapter gives an overlook to main forms of simulation used at RBBE and establishes the simulation status at BOSCH Producktie.

In the fifth chapter it is presented the role of simulation in the supply chain context and the global advantages of developing simulation software in this new context of global business.

Finally, the last chapter will be reviewed the work carried out presetting a conclusion and indicating futures procedures and vectors to follow about the new forms of simulation, prospect of improvements and boundaries of this technology.

2 Simulation

Simulation refers to a broad collection of methods and applications that mimic the behaviour of real systems, usually on a computer with appropriate software. In fact, “simulation” can be an extremely general term, since the idea applies across may fields, industries and applications.[2]

It is known that the manufacturing industry is one of the areas where simulation is used more widely as a decision making tool. Nevertheless, traditional simulation techniques are mostly not capable of simulating complex and distributed manufacturing systems. Since manufacturing processes became more complex and performed in distributed environments, distributed manufacturing simulation models are required in order to perform more realistic simulations [3]. However, simulation is still far from a perfect process. Because of the ways corporate priorities and specific products are made, the ways in which this technology is implemented and business value is obtained are unique to each company.

One of the major problems is that many simulation programs are not interoperable with other software, especially with the broad range of programs for other technologies and data management tools. Because the architecture of these programs is generally closed and rigid, programs simply do not talk to one another or exchange information well. Thus, users must go through inefficient processes of converting data, reworking models, duplicating representations and copying information from one system to another.

Another difficulty is that the programs are often aimed solely at particular user skill levels and specific types of analyses and may run only on certain computers. Users may find that some software is not well-suited to handle the wide range of complex problems and real world applications that engineers routinely encounter in their work. As a result, at many companies simulation may be performed sporadically in isolation from other tools and at small groups throughout the organization, adversely affecting the full integration of analyses into the product development process and not realizing the true potential of the technology.

This topic is especially important for BOSCH Produktie N.V. that is now, like many other companies, established in a global business environment. In this environment, understanding how simulation is controlled and operated when development sites are spread out in different continents is vital. The new supply chain methods impose additional pressure to make the most out of simulation. The question is: can manufacturing industries produce goods cheaper across several production locations and still use simulation as leverage to stay ahead of their competitors? The following sections will provide a summary of different simulation types and techniques and give an outline on the central complexities of the application and development of simulation in business.

2.1 Simulation Techniques

Jahangirian *et al* [4] is one of the most recent simulation studies that offers a broad and extensive picture of the role of simulation in manufacturing and business. This review uses a broad survey of the relevant literature, focusing on real world applications and demonstrates that in terms of techniques, discrete event simulation (DES) is still the most widely used form of simulation in manufacturing and business. It has been applied in a variety of industries for a wide range of operational management applications, including: scheduling, production planning, inventory control, process engineering, inventory management, SCM and project management. This suggests that DES has been appropriate for tactical and operational decision-making. In addition, DES tends to be convenient for detailed process analyses, resource utilization, queuing, and relatively shorter-term analyses.

Discrete-event simulation can be defined [5] as the modelling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time. These points in time are the ones at which an event occurs, where an event is defined as an instantaneous occurrence that may change the state of the system.

Based on the review [4], **system dynamics** (SD) is the second most widely applied simulation technique. Its use has been focused on such domains as policy and strategy development, project management, SCM, as well as knowledge management. As (Table 1) implies, SD's application areas are strategic decision-making level and analyses, high level perspectives, and qualitative analysis. A number of industries have adopted SD, including: semi-conductor manufacturing, automotive manufacturing, pharmaceutical and utility companies, as well as some service industries, such as Insurance, consulting, and software development.

System dynamics [6] is the use of a computer-generated system to represent the dynamic responses and behaviour of a real or proposed system. A mathematical description of a system is developed as a computer program that uses equations to represent the functional relationships within the system. When the program is run, the resulting mathematical dynamics form an analogue, usually represented graphically, of the behaviour of the modelled system. Variables in the program can be adjusted to simulate varying conditions in the system. Computer simulations are used to study the performance of objects or systems that cannot be easily or safely tested in real life.

Hybrid simulation is listed in third place, with just over 10% popularity. These studies combine various simulation techniques to solve a problem. The best known example of such an approach is the combination of DES and SD. This particular combination has focused on the concept of 'Enterprise Modelling and Simulation' where the impact of production decisions, evaluated using DES models, is investigated on the basis of enterprise-level performance measures. The SD simulation captures the long-term effects of these decisions, in a holistic sense that is appropriate for higher management levels, while DES provides detailed analyses of shorter-term decisions and actions. Another example of such integration is an hierarchical production planning architecture consisting of SD components for the enterprise level planning, and DES components for the shoplevel scheduling. This integrated approach is thought to hold promise for the next decade.

Agent-based simulation (ABS) is the fourth most popular simulation technique. One of the most common applications of ABS focuses on 'strategy' where, for example, each player of an industry is treated as an agent and every agent's strategic behaviour is modelled in relation to the classic strategy concepts such as Porter's 5-forces model. Similarly, the application of ABS in another common area – organizational development – addresses the modelling of human agents' behaviours, as well as communications inside an organization.

Monte Carlo simulation (MCS) is one of the earliest simulation techniques developed, but it has played a trivial role within the manufacturing and business domains. Its usage is mainly limited to 'static' problems or the solution of numerical problems of a stochastic nature, such as those found in property valuation and risk management.

Intelligent simulation is based on an integration of simulation and artificial intelligence (AI) techniques. The idea was put into practice perhaps for the first time in a tool called ROSS, which was developed by the RAND Corporation. The technique basically applies AI to tackle the volatility of real-life, or the over-complexity of some problems such as scheduling, making the solution approach quicker, sometimes real-time, as well as more manageable. Scheduling has been the most common application of intelligent simulation. AI techniques, such as artificial neural networks (ANN) and genetic algorithms (GA) have also contributed significantly to the development of simulation optimization methods.

Traffic simulation is the name of a group of simulation techniques specifically developed to solve traffic management problems. A relatively high number of papers using this technique prove the suitability of simulation to tackle transportation applications and traffic problems in particular.

The main theme of **distributed simulation** is to disperse simulation functions across a network, which is in harmony with the growing trend towards decentralization schemes within organizations. This approach is basically concerned with distributed architectures, such as high level architecture (HLA), and is currently applied to organizations and problems with a network structure, such as transportation (as a part of a hybrid technique), the electricity generation industry, as well as in SCM applications where the network structure of the chain plays a major role. Its frequent use in military applications has also been reported in the literature.

Simulation gaming (SG) is another technique that is receiving special attention from the education and training sectors and has been applied in such areas as incident management training. Simulation gaming has also shown its practical use where there are some pre-developed simulation games for specific industries, such as insurance, financial services, or supply chains.

Petri-nets were introduced as a graphical and mathematical tool to model computer systems. Generally, they can be used for describing and studying systems that are characterized as being concurrent, asynchronous, distributed, parallel and stochastic. Petri-nets support all the features needed to model processes. However, the use of this technique still conforms to no particular pattern, as it has been encountered in a wide variety of applications and industries from manufacturing, workflows and transportation systems.

Virtual simulation offers companies the ability to model and simulate a system in a three-dimensional, immersive environment. It usually forms part of a broader effort to develop virtual environments like virtual factories, so managers and engineers can have a more clear and reliable picture of any change's impacts on the system. The data in such an environment is shared in analyses of various activities, including product development, production planning, assembly analysis, work study, workplace design, operation simulation and plant layout.

Table 1 Applications of simulation techniques in manufacturing and business

Application	Simulation technique	Industry sector
Assembly line balancing	DES	Computer hardware
	Other hybrid techniques	Optic lens assembly
Capacity planning	DES	Generic service industries
		Generic part manufacturing
		Pump production
		Transformer manufacturing
		Beverages
	SD	Extruded food production
	Monte Carlo simulation	Electricity generation
	Petri-net simulation	Generic part manufacturing
	Other hybrid techniques	Financial/insurance and education
Cellular manufacturing	Virtual simulation	Automotive
Transportation management	DES	Urban traffic management
		Stationary production
		Concrete transport
	ABS	Railway transport
		General transport
	Petri-net simulation	Generic part manufacturing
	Traffic simulation	Traffic control, freeway traffic control
		City logistics
	Hybrid (SD&DES)	Traffic control
	Other hybrid techniques	Highway traffic control, urban traffic control
	Other techniques	Airport management
		Travel navigation
Facility location	Other hybrid techniques	Transportation
Forecasting	SD	Aircraft manufacturing
Inventory management	DES	Generic part manufacturing
		Automotive
		Construction
		Chemical products
		Recycled parts
		Insurance and education
	Monte Carlo simulation	Nuclear and spacecraft
	Other techniques	Retailing
Just-in-time	DES	Generic part manufacturing
	Intelligent simulation	Generic part manufacturing
Process engineering-manufacturing	DES	Ship building
		Automotive
		Pharmaceuticals
		Generic part manufacturing
		Electronics
		Aluminium gas cylinder
	SD	Automotive
		Generic part manufacturing
	ABS	Generic part manufacturing
	Monte Carlo simulation	Generic part manufacturing
	Petri-nets simulation	Generic part manufacturing
	Virtual simulation	Generic part manufacturing
		Electronics
	Intelligent simulation	Generic part manufacturing
		Electronics
	Other hybrid techniques	Generic process industry
	Other techniques	Various manufacturing industries
		Beverage
Process engineering-service	DES	Retailing
		Generic service industry
		Printing
		Consulting
		Distribution
		Container terminal
		Construction waste handling
		Construction
	SD	Logistics
		Insurance
	Distributed simulation	Electricity generation
		Information and communications

Table 1 (continued)

Application	Simulation technique	Industry sector
Production planning and inventory control	DES	Electronics
		Generic part manufacturing
	ABS	Generic part manufacturing
	Distributed simulation	Aluminium production
		Heater manufacturing
		Automotive
	Hybrid approach (DES&SD)	Generic part manufacturing
		Electronics
	Other hybrid techniques	Aluminium sheet production
Purchasing	DES	Energy
Resource allocation	DES	Transportation
		Generic manufacturing
	ABS	Shipping terminals
	Monte Carlo simulation	Jet engine repair
	Distributed simulation	Electricity
	Intelligent simulation	Generic manufacturing
	Hybrid approach (DES&SD)	Semi-conductor manufacturing
	Other hybrid techniques	Research
	Other techniques	Construction
Scheduling	DES	Generic part manufacturing
		Semi-conductor manufacturing and electronics
		Container terminals
		Airline
		Re-manufacturing
		Printing
	ABS	Generic part manufacturing
	Monte Carlo simulation	Electronics
	Petri-nets simulation	Generic part manufacturing
	Intelligent simulation	Generic part manufacturing
		Computer hardware
	Other hybrid techniques	Generic part manufacturing
	Other techniques	Generic part manufacturing
Strategy	DES	Furniture manufacturing
	SD	Electronics
		Generic part manufacturing
		Consulting
		Automotive
		Electricity generation
		Financial and aircraft manufacturing
		Information and communication
		News publication
		High-tech
		Chain restaurant
		Aeroengine manufacturing
		National energy management
		Construction
	ABS	Information and communication
		Electricity
		Generic part manufacturing
	Simulation gaming	Financial and insurance
	Monte Carlo simulation	Generic part manufacturing
		Energy
	Hybrid (SD&DES)	Electronics
	Other techniques	Information and communications
Supply chain management	DES	Generic part manufacturing
		Chemical products
		Food
		Notebook computer
		Retailing
	SD	Electronics
		Generic part manufacturing
		Machine tools manufacturing
	ABS	Mold manufacturing
		Appliance/electronics/computer
		Computer hardware

Table 1 (continued)

Application	Simulation technique	Industry sector
		Generic part manufacturing
	Other hybrid techniques	Trading
		Generic part manufacturing
		Packaging/machine manufacturing/iron metallurgy/apparel manufacturing/dairy
Workforce planning	DES	Franchised food
		Electronics
		Airplane manufacturing
		Call centres
	Other hybrid techniques	Steel production
Maintenance management	DES	Generic part manufacturing
	Monte Carlo simulation	Generic part manufacturing
	Virtual simulation	Machine building
Knowledge management	DES	Generic part manufacturing
		Aircraft manufacturing
		Construction
	SD	Generic part manufacturing
		Pharmaceutical
Project management	DES	Aircraft maintenance
		Oil and gas
		Chocolate
		Construction
		Software development
		Consulting
	SD	Semi-conductor manufacturing
		Software development
		Generic projects
		Construction
	Monte Carlo simulation	Software development
		Construction
	Petri-net simulation	Construction
	Intelligent simulation	Construction
	Hybrid approach (DES&SD)	Software development
Organizational design	DES	Generic part manufacturing
	SD	Pharmaceutical
	ABS	Generic part manufacturing
	Simulation gaming	Information and communications
	Other hybrid techniques	Generic manufacturing
	Other techniques	Trading
		Pharmaceuticals
Management training and education	DES	Education
	SD	Education/software development
	Simulation gaming	Education
		Construction
		Clinical instrument manufacturing
	Distributed simulation	Education
	Virtual simulation	Education/construction
	Other hybrid techniques	Education
	Other techniques	Education
		Construction
Financial management	DES	Electronics
		New-product-development
	Monte Carlo simulation	Stock markets
		Property
		Accountancy
Quality management	DES	Software development/education
		Automotive
	SD	Computer hardware
		Construction

2.2 Differences in Simulation

Several large companies around the world have successfully adopted simulation tools as an integral business instrument. However, the way in which simulation is introduced, established, practiced and developed is different in each company and its uses can diverge considerably.

Many US companies have developed their simulation activities over many years, while in Europe the use of simulation technology remains relatively immature. In Japan, simulation is still linked to the possibilities of new expertise used largely to expose operational inefficiencies and waste in the manufacturing process [7]. This is mainly to ensure productivity improvement, but its implementation and progress are correlated, above all to the technical aspects of factory incorporation.

According to [8], American companies already use simulation as an integral part of the design and development process. European companies apply it in more specific applications and the general consensus is that it is too complex, too difficult to use and takes too long to obtain good results.

Factors hindering simulation development created in most cases a gap between US and Europe, the contributing factors of which are explained in the fishbone diagram in (Fig.1) US industry has identified a need for simulation and thus undergraduate courses (in, for example, engineering) teach a significant level of simulation. In the US, simulation vendors and industry have both managed to create a community of users and conferences actively enhancing the use of simulations. In Europe, on the other hand, very few mechanisms of promotion have led to a lack of exposure and awareness of the potential and importance of simulation.

Extensive research by American universities and industry has supported the development of simulation technology. Several companies lead the way in the use of simulation, enabling competitors to recognize its capabilities and benefits. US managers are more conscious of the benefits of simulation, therefore providing more support and backup. On the other hand, some European managers still feel sceptical about simulations benefits, often because of limited education and/or experience. In addition, more funding is available in America to go further in the application of simulation capabilities to new areas of business. Furthermore, the lack of software vendors in some European countries limits the support and close contact needed for industry to introduce and exploit simulation.

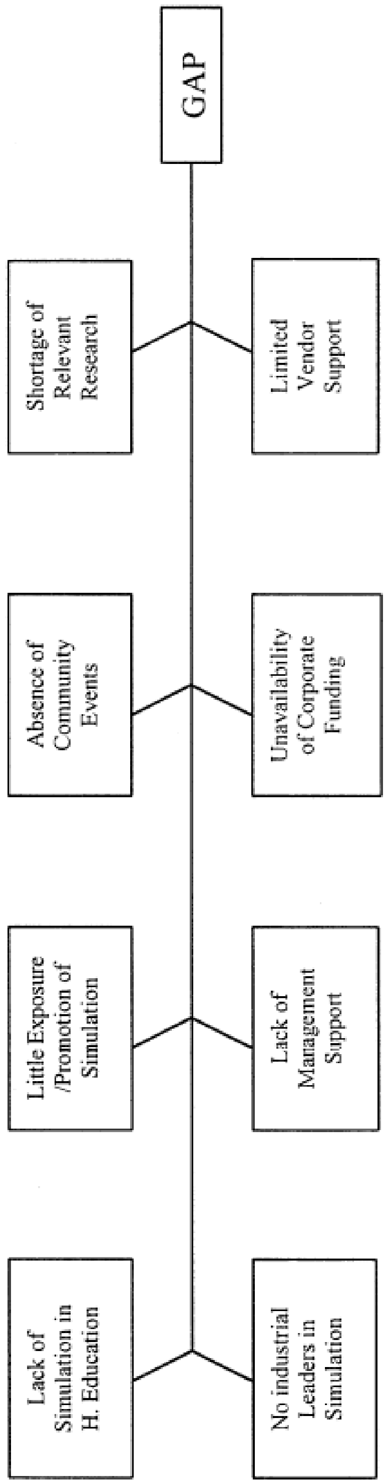

Fig. 1 Factors for gap differences in simulation use

2.3 Simulation costs

Despite the availability of modern era simulation technology, in a competitive business the most elegant product design it is no longer sufficient if there are no established means of converting ideas into cost effective manufacturing systems. Companies that employ simulation techniques should consider that the end result is cost saving strategies or new product forms, with the purpose of added value income expansion. However, this effect is often hard to determine and the financial conclusion most of the time is not obvious. Most of these strategies have generally focused on product and process design issues or are based on capability concerns. They have been historically justified using cost savings calculations, focusing on easily quantifiable costs such as raw material savings or the manufacturing or assembly operations no longer required.

J.A. Barton *et al* [9] argued that neither the focus of the strategies nor the means of justification are adequate. Product and process design strategies should include both capability and capacity concerns and justification procedures should include the financial effects that the product and process changes would have on the entire company. The authors stress the need to take a more holistic view of the problem and examine how new and innovative strategies ought to be used for more a comprehensive understanding of the enterprise value of simulation.

This topic has become even more important as companies are now established in a fully global market in which the range of applications and the scope of evaluation mechanisms have to be integrated. In addition, recognizing simulation's value is even more complex when one takes into account the interdependencies of decisions in areas such as product design, configuration, control systems and supplier relationships, making this matter particularly relevant to strategic issues.

Currently, few tools are available to estimate cost savings at an enterprise level. Some new systems are appearing but their ability to generate financial performance metrics are either non-existent or limited to simple cost models. In fact, the scope should not be limited only to areas within manufacturing, but should include engineering and other key business functions. This implies that these new forms must be capable of evaluating the impact of a decision, made anywhere in the company, on the performance of the whole business and not be constrained by the range of decisions that can be tested by the user; they should be able to cope with any level, from the strategic to the operational. This means determining the impact across all significant elements of the company's internal systems, and even the inclusion of necessary external elements such as suppliers and customers. Since the evaluation is to be made in a business context, then it follows that it is necessary to include all the normal financial performance information routinely generated by any company's accounting system.

2.4 Control in simulation

The possibilities of computer simulation are not currently being fully exploited. At the moment, computer simulation is limited in its use and application. One of the major limitations of simulation can be explained by the fact that operational decision making processes, and its impact on the production system, are not taken into account during simulation because existing tools are not adapted for decision and control modelling.

Traditionally, simulation has been used for offline decision-making. One of the limitations of its use in this context is the considerable amount of time spent in gathering and analyzing data. Consequently, this has resulted in decision makers relying on simulation primarily for offline decision support and not for the critical online decision making that may arise [10]. In real time control, the three key issues are data acquisition, quick response and instantaneous feedback. The major components of online simulation systems generally consist of a data acquisition module, a simulation model and a cell controller. Given these limits, existing tools fall short of offering effective integration control into process production. In order to enhance the capabilities of computer simulation and make it more responsive to today's industrial needs, it is necessary to find a way of introducing such control into simulation by pursuing generic and applicable concepts.

Recent studies [9] suggest this is possible in all major types of manufacturing system processes: operational, informational and decisional.

One common procedure is to initiate a modification of a parameter possible during simulation runs. Nevertheless, this is often not executed according to a control logic. A good control requires the introduction of feedback loops around each production resource. As these loops have currently not been introduced in the models, proper control requires many experiments in order to optimize the results. In addition, simulation tools use concepts that are often too complex for most potential users. Therefore, the use of simulation in companies remains for the most part irregular and limited in scope.

Some simulations focus on the formulation and solution of problems by trial-and-error methods. As a result, the simulation process is iterative and often reveals important information and new insights into the problem area. During this iterative procedure, the relationship between the system under study and the model are continually redefined. Simulation and modelling are therefore inextricably linked within the simulation process. Therefore, the more experienced practitioners use experience.

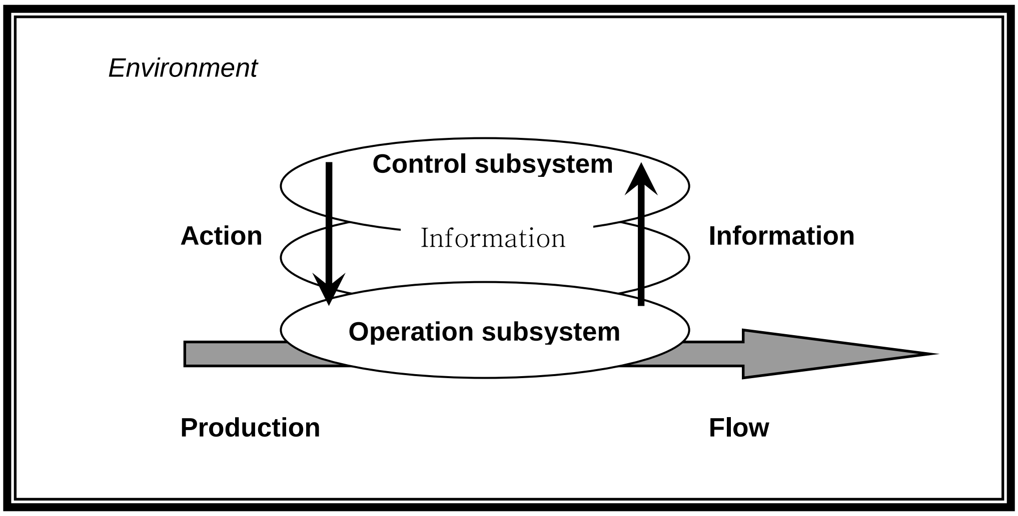

Fig. 2 Control in a simulation manufacturing system

Manufacturing systems are by nature complex and analytic methods cannot be always applied; a systemic analysis is thus necessary to apply to simulation. Basically, a production system is divided into three subsystems: physical, informational and decisional. Nevertheless, as simulation models are based on information, only two subsystems are considered: operational and control.

To design, organize and create control in manufacturing systems, managers must take the following aspects under consideration: the diversity and heterogeneity of production flow, production space optimization, production process organization and management simplification.

2.5 Data management

The developments of simulation techniques have been improving for many years. In the past, discrete-event simulation dominated the market. It was not until the mid 1980s that different types of simulation software began to emerge. This was due mainly to new technological capabilities such as computer and 3D modelling visualization. The emergence of this new simulation software was seen as a replacement for the traditional ways business develop both products and processes within the facility environment.

However, it is increasingly difficult to select software for specific processes, due to the diversity of simulation software available. The application boundaries of different simulation types are unclear; therefore, their function is imprecise, making the proper utilization of simulation difficult. Once classification has been determined, the integration of different simulation types and management can present many problems that need to be addressed. The management of this integration is crucial to maintain data integrity and control, without which the possibilities for effective integration cannot be fully explored.

The 3D capabilities of simulation can provide huge benefits and this fact has been acknowledged as a recognized asset for large companies. However, there is some confusion as to the overall utilization capabilities and integration that is now available. The uniqueness of each simulation type is defined by the way in which key functions are combined the key simulation functions of each proposed simulation type. To be able to apply simulation to a business, the ability to understand business in detail and understand the attributes of simulation is crucial. The literature review and survey of simulation raise certain issues that require further investigation to ensure the proper application of simulation. Aerospace technology is a case in point, as aerospace companies deal with all these issues and aerospace is one of the industries with more background in and experience with simulation.

In this way, according to [11], data transfer and data integrity are crucial elements in the formation of a practical simulation environment. Through this practical integration, they must be robust enough to allow for full product and process data transfer. In data transfer, the amount of detail required has to be carried across by the user of different data formatting techniques (i.e., data translators).

The question now is: would this single digital environment be of use, and would the problems encountered in its implementation outweigh its benefits. The integration and management of this simulation environment are important areas of concern, as the wrong approach will ensure failure.

Data transfer can be divided in two kinds:

1) **Transfer of product data**: geometrical data (dimensional characteristics of components, sub-assemblies, etc.)

2) **Transfer of process data**: numerical data (spreadsheets, Gantt charts of cycle times, etc.)

In the transfer of product data, product data should be transferred using translators, which allow the data to be formatted and transferred as required. This means that it carries across all attached data; for example, the transfer of sub-assembly data from CAD software to assembly sequence simulation. The sub-assembly must have in its structural capacity the ability to allow for the selection and manipulation of any part contained within that sub-assembly.

The practical difficulty here is that different simulation software has largely been incompatible with each other and software types like CAD and others use the limited number of standardized data formats available, restricting the opportunity for data exchange. Neutral formatting of product data is now possible, with the emergence of translators and various other software. The software receiving the product data also needs to be able to accept these data as a function of its own integration capabilities. Building these integration capabilities into simulation software would also allow the transfer of data between one simulation type to another using the same neutral translators.

For the transfer of process data, simulation software has been developed to allow for integration with commercial spreadsheet packages like Microsoft Excel, etc. The data tables can be read and the spreadsheets manipulated to fit into the internal process of simulation. Due to the extensive commercial use of these spreadsheets, it may be easier to use this software directly, by using simple programming. These process data may provide all the information simulation software may need, but the level of detail of these data may prove to be problematic. If these data tables are too detailed, for example, they would need to be formatted before use. Calculations would need to be performed and presented in the right format to ensure that it is correct, either using the internal spreadsheets or directly in a commercial spreadsheet.

Both data transfer techniques are made more difficult due to the iteration processes performed by simulation software, due to design changes and business constraints. The management of this data transfer and iteration process is important to ensure that the simulation environment functions properly.

Integration is purely associated with data transfer and does not address the issue of data management. Concurrent manufacturing practices have been, by their nature, overlapping in their applications. Each area has its own particular application, but it may also rely on the input from other areas to ensure accurate and precise results. These application areas utilize simulation for its experimental and analytical value. Data management is essential to maintain the progressive development of data in the various application areas and therefore for various types of simulation.

Direct data transfer between concurrent simulation types would cause more problems that it would solve. With direct access to data from one simulation type to another, there would be no guarantees that the data transferred are correct. Product data modification and/or manufacturing process data iterations can be managed to highlight any changes through the implementation of control mechanisms through all processes, as stated earlier.

Data management is necessary for the successful integration of all designing, planning and decision making issues. In order to develop the optimal solution in product and process refinement, all functions need to be able to respond directly to any changes necessary. This capacity to respond leads to higher quality and productivity.

3 Bosch Producktie

Fig. 3 Bosch Tienen Factory Picture

3.1 Bosch introduction

Robert Bosch Produktie N.V. is a part of the Bosch Group, in the Electronic Drives section of the automotive technology division. Located in Tienen, Belgium, it was founded in 1973. Last year, it occupied an area of 173,512m^2 with 1486 employees. Robert Bosch Produktie N.V.'s main activity is the production of wiper-blades systems. It has more than 108 clients and 165 suppliers. In 2009, the production volume was 79 million wiper blades parts with a total net sales over 264 million Euros.

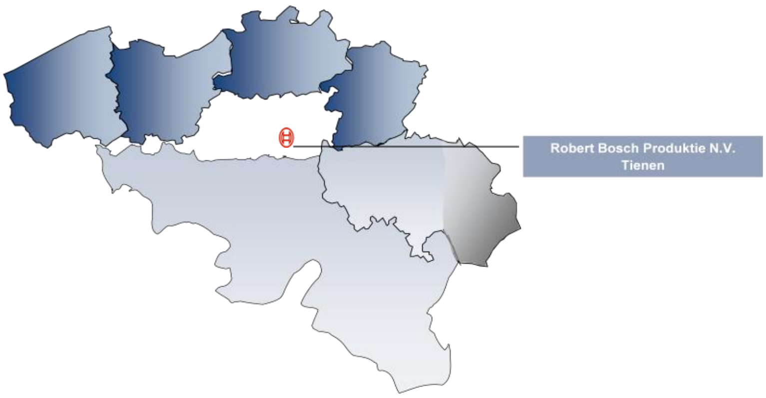

Fig. 4 Robert Bosch Producktie location

3.2 Wiper blade

The wiper blade is composed of two flexible metal springs (tension strip), which are connected at the ends by connecting bridges. This builds the vertebra. Inside the vertebra runs the rubber profile, which is fitted out for aerodynamic and over spray reasons with a spoiler. Nearly in the middle of the blade the adapter is positioned [12].

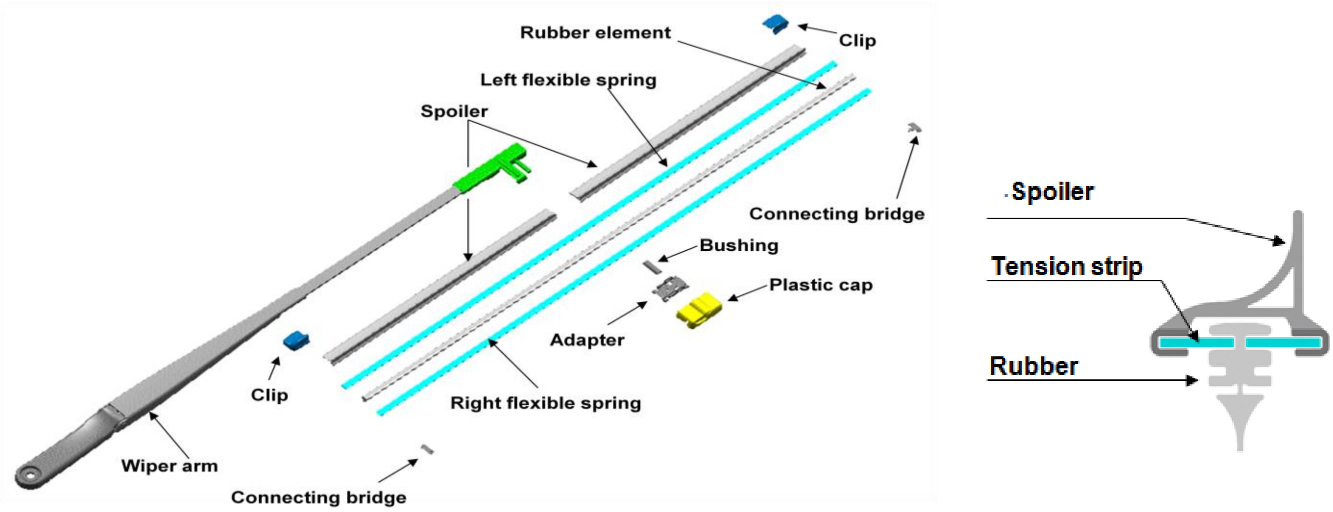

Fig. 5 Wiper blade

3.3 Bosch product range

The company produces a wide variety of adapted solutions for wiper blades, for several leading motor vehicle companies. This is irrevocably linked with each market selection and customer-specified requirements. Several product lines are produced and manufactured to compete in a global market, where BOSCH expects to lead in performance and to match its rivals' technological investment in the research and development of new wiper systems.

The aerotwin blade is BOSCH's latest wiper blade product, with several new features. Table 2 shows BOSCH's main product line, with visual examples of the most important existing wiper blade models.

Aerotwin	Twin/Excel	ME 3	C 2

Table 2 Main wiper blade product range

4 Simulation at Bosch

4.1 Simulation status at Bosch

It is now safe to conclude that BOSCH and RBBE in Tienen have reached a mature level of the use of simulation. The incorporation of this technology can be seen in the form of their research and development activities as well in their general use in manufacturing support and planning. From the literature review, common simulation practices and other data analyses can be isolated and identified as reasons for their high execution level of simulation based technologies:

- The strong role of competitors in the automotive component sector, as well as a present dynamic and short life market cycle

- Management awareness of the importance of simulation practices, especially in order to ensure future added value in new products and financial sustainability

- Access to qualified human resources and strong connections with both foreign and local universities, along with the possibility of maintaining recent post-graduate students for the completion of thesis internships and PhD studies, thus supporting BOSCH with the latest academic methods and the prospect of continuing research at competitive financial levels

- Good relations with software vendors and external institutions; these coordinated partnerships provide assistance for the development of technology in research and new production methods

4.2 Beam definition for Aerotwin wiper blades

For beam definition, BOSCH uses a group of simulation tools that allows the delivery of an optimized solution taking into account a variety of data relations. First, a theoretical windscreen is analyzed; this information is usually provided by the client or it can be measured and examined inside the company's facilities. Then, a wiping field on the windscreen is defined in order to assess the working array assortment of the new beam. In this way, specific wipe positions can be distinguished and connected to the beam performance study, on both the driver and passenger sides.

Next, a more theoretical examination takes place, with the windscreen radius and curvatures especially in the most critical positions. Using this information, , the simulations provide more accurate and precise results, since the radius paths are taken into account for the definition of the wiper blade beam.

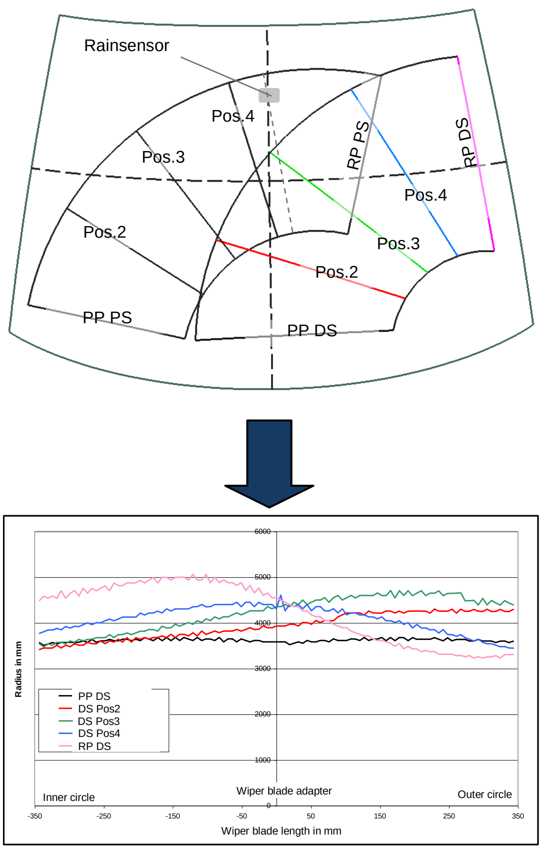

Fig. 6 Windscreen analyses

After this process, simulation aided technology continues to facilitate and optimize the outcome of the beam geometry. Simulation tools enable the unification of the radius and curvatures in order to reach an optimized beam solution.

This creates, in cooperation with other inputs, a distinctive force pressure distribution for each beam definition. Using this method discloses a wide range of possibilities. Several adapted forms can be shaped and tested to provide a unique product for each requirement. Figure 7 shows a part of the simulation work flow. Here, some inputs work collectively in order to achieve adapted and personalized geometries, with the ultimate purpose of putting together the best theoretical display radius and curvature in each section. This way, the force pressure requirements guarantee the best performance for each final wiper blade product.

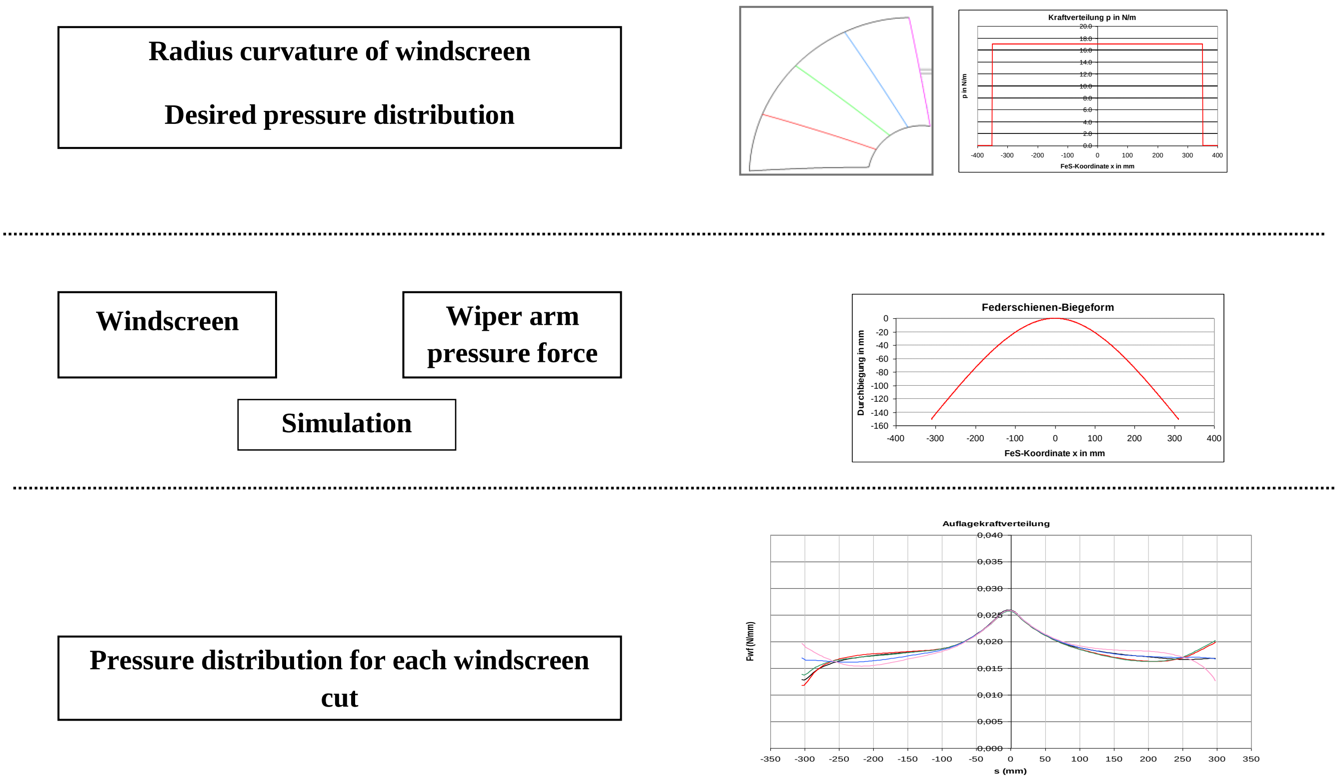

Fig. 7 Simulation workflow

4.3 Windscreen simulation

The windscreen, being the working surface of the wiper blade, is an absolutely essential element for the wiper system. Thus, it is decisive to create new and innovative forms of analyses that can potentially generate the best outcome solutions, for both the end result of the wiping, as well as modern additional features that can enhance the product profile.

For the windscreen analysis, technology metric software is used that generates a stand-alone digitalization solution. It uses a projection of structured white light, which automatically performs a reference matching of different scans using marker measurements of the whole windscreen. On this basis, simulations can then be carried out, in order to reveal possibly problematic areas of each section that can generate un-wiped areas. This can help advance other tests, which involve more sophisticated simulation methods, to perform experiments and trials in order to achieve a direct result that will match the scanned areas.

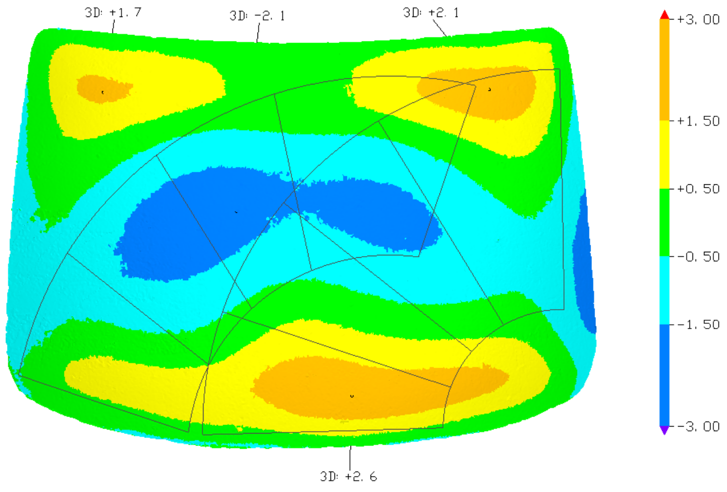

Fig. 8 Windscreen comparison in 3D

4.4 Aerodynamics

Located outside the car's bodywork, the windscreen wiper blade is entirely exposed to external aerodynamic effects of the natural elements. Wind and speed are some of the main aerodynamic components that can affect a wiper blade's performance. The two main aerodynamic forces that can affect performance are: drag force; which tends to brake the wiper blade during the wiping down; and lift force, which tends to lift the wiper blade up. Lift force is one of the most critical strictures for wiping quality at high speed. Indeed, the flow is often strong enough to pull up the wiper arm and blade and leave unwiped areas on the windscreen. Computer simulation tools have a pivotal role to play in aerodynamic studies. Several parameters influence lift force: the speed of the car, arm shape, the position of the wiper blade on the screen and the car's geometry.

A computation is performed by modellizing the front half of the car (from the bumper to the main column) at speeds ranging from 180 to 250 kph in order to study and overcome problems caused by aerodynamic forces. The main task here is to evaluate the consequences and actions of the lift force and to optimize the system in order to reduce it.

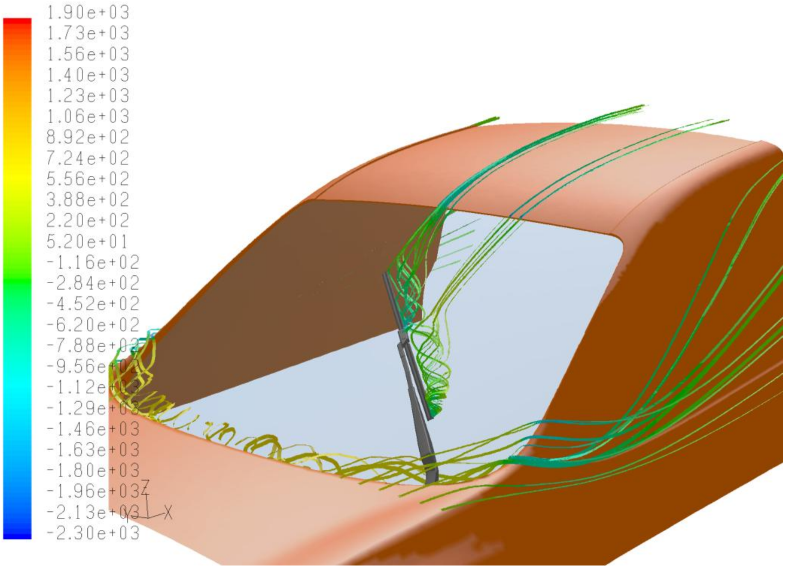

Fig. 9 Aerodynamic Simulation

4.5 Simulation worldwide expertise

There are several more simulation applications that operate throughout other departments and even in other locations across the globe. Besides the main site in Tienen, BOSCH and RBBE work together with other BOSCH GROUP facilities to develop their products. Different methods work together in order to consolidate knowledge in diverse areas; the goal, however, remains the same. Combine these locations around the world endeavour to find innovative forms to add value to new product design. These locations each contribute different competences that they have acquired over the years in special technical fields. Bringing together expertise from several areas is now crucial in simulation use, and undoubtedly will be a challenge in the near future.

This last section will give some insight into and illustrate different types of simulation software that are used in other BOSCH locations, as well as try to sum up the condition of simulation and new computing technology in the wiper-system industry.

It is now possible to execute the modellization of the 3D wiping movement of the wiper blade on the screen and to simulate the contact pressure and contact angle over the entire wiping area. Several new parameters are taken into account in these innovative simulations:

- Mechanical behaviour of the rubber
- Geometry of the profile
- Beam characteristics
- Geometry of the windscreen
- Temperature, friction, and so on

The aim is to predict the wiping quality on a particular screen and to detect in advance unwiped zones and possible difficulties during wiping under certain conditions (e.g., temperature, friction, wetness, etc.).

Because of advances in electronic and computing capacity, numerous types of simulation software can now be used to development new profiles, adapt new materials or improve existing profiles for better performance. Finite element methods and current CAD software can perform these kinds of simulations. Other software, like Abaqus and Matlab, can also improve to the simulation workflow and generate the modellization results. In this way, new possibilities are disclosed and new phenomena can be studied. Furthermore, new relevant parameters can emerge, such as:

- Rubber characteristics
- Rubber profile shape
- Contact pressure

New forms and geometries are produced and tested quickly and simultaneously with the other BOSCH locations. Information technology connects these efforts and is able to optimize new profiles and generate innovative geometries and shapes, which can then be experiment into new outputs like force strain, friction deformation and others.

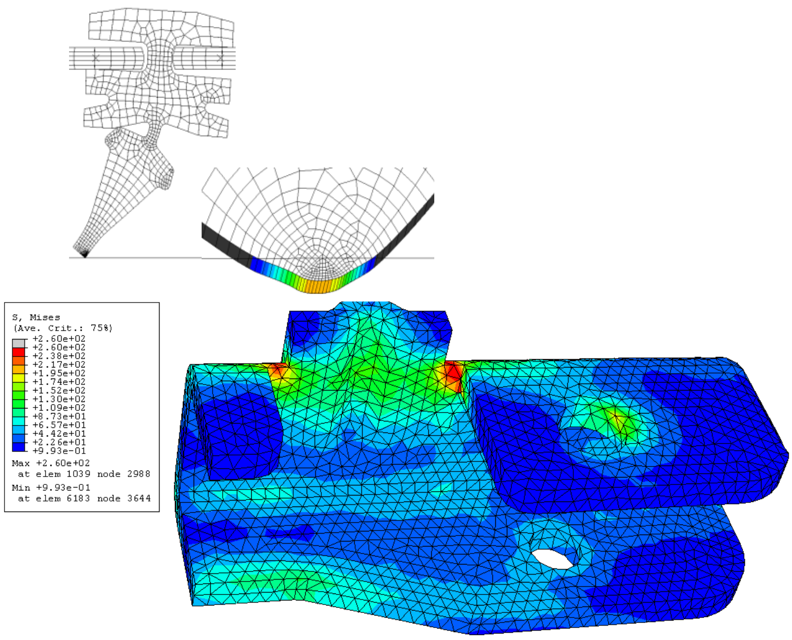

Fig. 10 Advance profile simulation

5 Simulation in the supply chain management

5.1 Supply chain management

Globally engaged companies are realizing that the efficiency of their own business is heavily dependent upon collaboration and coordination with their suppliers as well as with their customers. This external perspective is currently addressed under the broad concept of supply chain management (SCM), which is concerned with the strategic approach to dealing with trans-corporate logistical planning and operation on an integral basis. Adopting a SCM strategy means applying a business philosophy where more industrial nodes along a logistical network act together in a collaborative environment, pursue common objectives, continuously exchange information, but at the same time preserve the organizational autonomy of each unit. This business vision is applied to different industrial processes and implemented through different policies. Integrated management frameworks support the development of collaboration across multiple tiers through mutual design planning and execution along the entire supply chain [12].

This definition provides a new perspective on logistical functions, where such a broader perspective is needed. Companies now require a progressive shift from an intra-company view to a more externally oriented logistical integration, supported by new systems and functions.

The article [13] gives great emphasis to the term 'integration'. The author of the article states that this term often generates a lot of confusion and is frequently misinterpreted. It is widely recognized that the last decade provided companies with the opportunity to smooth out their physical boundaries using SCM methodology. However, as opposed to the classical morphological scheme in corporate logistics, the SCM scheme requires, among other things, the alignment of network strategies and interests, mutual trust and openness among tiers, a high intensity of information sharing, collaboration on planning decisions and shared IT tools.

These requirements often represent major hurdles inhibiting the full integration of a logistical chain. Even in the presence of a strong partnership and mutual trust among logistical nodes, there are in practice evident risks of potential conflict between local versus global interests and a strong reluctance to share common information related to production, planning, scheduling, inventory and capacity levels.

5.2 The role of simulation

From an IT perspective, a new wave of solutions is arising with the main objective of overcoming these sorts of organizational and information hurdles, which can seriously jeopardize any cooperative effort. Among these new solutions, simulation is undoubtedly one of the most powerful techniques that can be applied, as an important support for production engineers in validating new decisions. Nowadays, knowledge of simulation is considered one of the most important competences to acquire and develop within modern enterprises in different process.

From this point of view, there is a strong need to adopt distributed collaborative solutions, which can at the same time preserve local autonomies and the privacy of logistics data. Moreover, these solutions must necessarily be platform independent and easily interfaceable with companies' legacy systems. The literature describes numerous methodological and practical approaches to new forms of distributed simulation. In these cases, the interaction between participants and tools are explicitly and globally defined.

5.3 Parallel distributed simulation

It is frequent to think simulation being made by an individual sitting at a desk working on a computer. The problem with this scenario it is somewhat archaic an inefficient. Moreover it is becoming increasingly harder to construct flexible simulation software capable of evaluating complex system architectures and traditional simulation is also expensive [14].

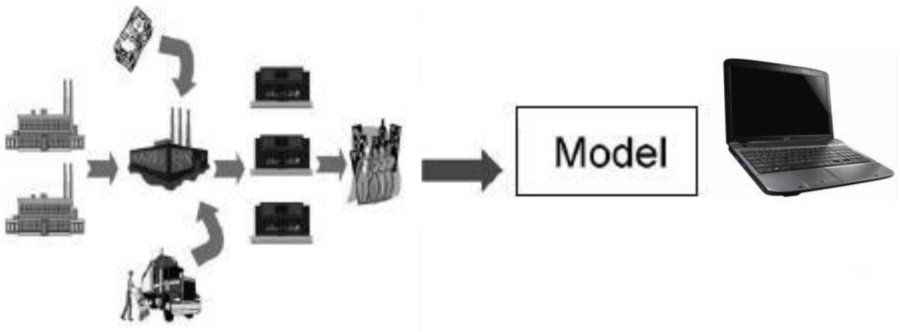

Fig. 11 Local simulation paradigm

In Fig.11 is possible to observe the traditional local simulation model. Here the main producer has suppliers logistic partners and retailers that deliver the final product to the client. All the steps are well distinguished and a simulation model is made separately.

However the combination of the latest technological improvements, and as stated before, the modern business beliefs like SCM have created a new set of requirements for companies.

These requirements are profoundly changing the traditional paradigm underlying the world of simulation. In the literature [13], there is a progressive shift of research and application work from local, single-node simulation studies to modelling in a more complex, logistical channels system. Generally, simulation in such systems can be carried out according to two structural paradigms: using only one simulation model, executed over a single computer (local simulation, as illustrated in Fig.11) or implemented using multiple models, executed over more processors (multiple computers and/or multi-processors) in a parallel or distributed fashion.

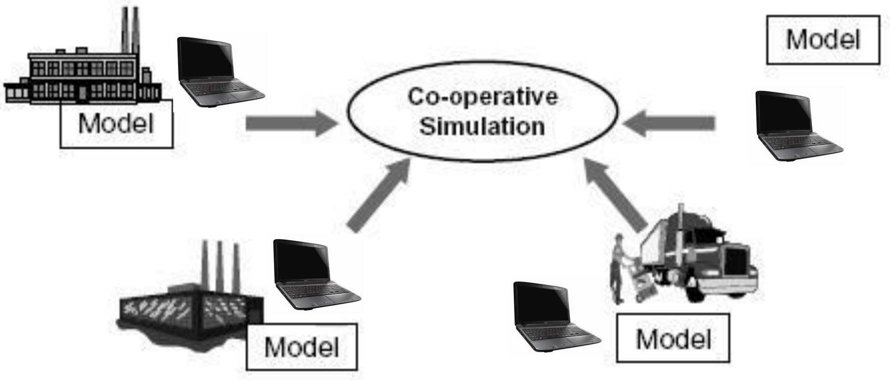

Fig. 12 Parallel and distributed simulation paradigm

Distributed simulation (DS) is concerned with the execution of simulations on geographically distributed computers interconnected via a network. Parallel discrete-event simulation (PS) is concerned with the execution of simulation programs on multiprocessor computing platforms. Although this latter type of simulation is only used for the discrete-event simulation techniques, opposed to distributed simulation, there are a broader range of techniques that can be applied

Both types involve the execution of a simulation made up by several sub-simulation models, which are executed in a distributed manner over multiple computing stations (see Fig. 12). Hence, it is possible to use a single expression, PDS, referred collectively to both types. The PDS paradigm is based upon a cooperative and collaborative concept, in which each model co-participates in a single simulation execution, as a single decision-maker of a ‘‘federated’’ environment.

5.4 Distributed simulation background

According to [15], cuts in the defence budget provided the United States Department of Defence (DoD) with the original motivation to explore new training options. This led to an examination of simulation and modelling technologies, which were gaining wider success and popularity due to improvements in the speed and affordability of computing technology. The field of distributed simulation has first evolved since it emergence in the 1980s. Since then, the defence community has been a driving force in defining and developing distributed simulation. These progresses were largely driven by and created within the US DoD, mainly to develop simulation-based training, providing potential solutions to a number of growing problems in defence-related training activities, such as:

- **Costs**: It is expensive to provide an adequate amount of real hardware for training purposes; for example, the costs involved in using aircraft or firing real weapons. It is possible enlarge and use a greater number of simulators than a number of real hardware for the same cost.

- **Impracticalities**: There are logistical difficulties in conducting certain live training exercises involving, for example, representatives from multiple forces (Navy, Army, etc.) or international participation. Another impracticality concerns the potential non-existence of hardware, which may still be in the prototype development stage. Using simulation, it may be possible to train staff in advance of the final product being available.

- **Political and social**: There is an increased sensitivity to military activities among the public, particularly the use of land to conduct live training.

Fig. 13 illustrates what may be considered as a typical distributed environment [14]. This fictitious configuration suggests a joint training exercise of

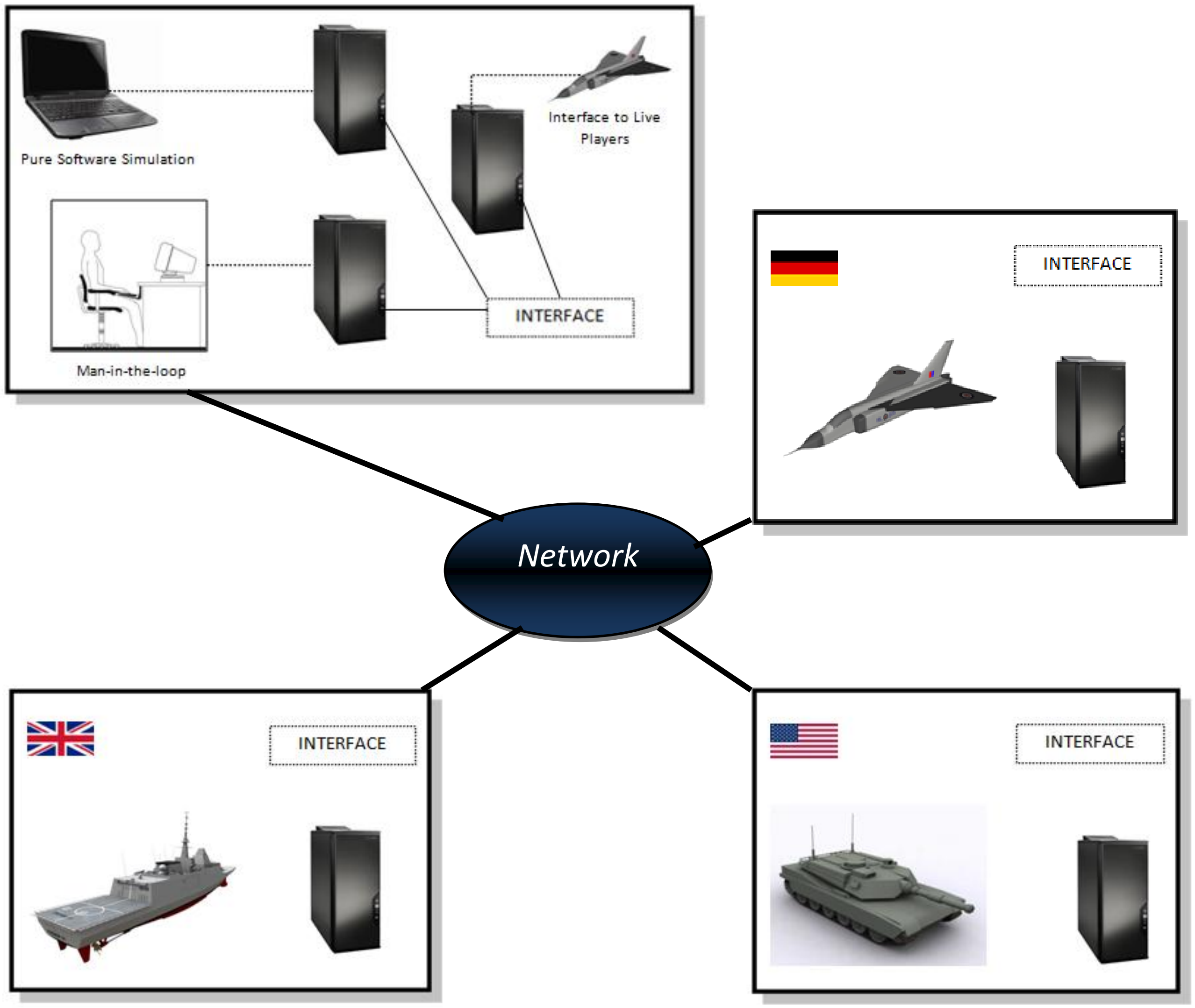

Fig. 13 DS training environment

international participants. In this particular example, the navy (UK), airforce (Germany) and army (US) units simulate entities at different locations. These entities would share a common artificial environment in order to achieve common goals, as stipulated by the training exercise.

In this particular case, one can see some of the central attributes that are accepted characteristics for different types of distributed simulation:

- **Live**: involving interfaces with real people and equipment; here referred as 'man-in-the-loop'.

- **Virtual**: involving people interacting with simulated systems.

- **Constructive**: entirely computer-generated simulations, i.e.simulated people operating in a simulated environment.

However, the major breakthrough here is the interoperative network used to describe the interaction between simulation participants. This is most significant, as it implies an awareness of the capabilities of the other participants, in addition to the level of communication used, concerning the need to agree on the format and the frequency of the environment's common view across simulations.

5.5 Distributed simulation objective

Initially intended for use within the US DoD, subsequently there was an increasing awareness that distributed simulation was relevant to the wider simulation community, both outside of the US and outside of the defence community.

The article [13] isolates the need for a distributed execution of simulation across multiple computers in four main reasons.

- **To reduce execution simulation time**: A large simulation can be split into more models and thus executed in a shorter time.

- **To reproduce a system geographic distribution**: Some systems (such as supply chain systems or military applications) are geographically distributed. Therefore, reducing them to a single simulation model is a rough approximation. By preserving the geographic distribution, the execution of a PDS over distributed computers enables the creation of virtual worlds with multiple participants that are physically located at different sites.

- **To integrate different simulation models that already exist and to integrate different simulation tools and languages**: Simulation models of single local sub-systems may already exist before designing a PDS (e.g. flight simulators in military applications, but also local production systems in a supply chain context) and may be written in different simulation languages and executed over different platforms. By using a PDS paradigm, it is possible to integrate existing models and different simulation tools into a single environment, without the need to adopt a common platform and language and to re-write the models.

- **To increase tolerance of simulation failures**: This is a potential benefit for particular simulation systems. Within a PDS, composed of different simulation processors, if one processor fails, it may be possible for others processors to go on with simulation runs without the down processor.

5.6 Protocols

Parallel distributed simulation, in its practical execution, requires a framework which enables the modelling of the information shared and synchronicity among the different single local simulations. From the literature [13], it is possible to distinguish two different PDS frameworks, separated by their basic coordination logic.

- **A network structure**, based on a distributed protocol logic, in which single nodes are mutually interconnected (Fig 14a).

- **A centralised structure**, founded on a central logic, in which a single process manager is responsible for linking participant nodes (Fig 14b).

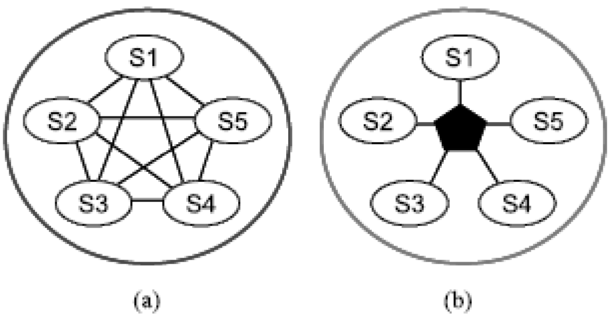

Fig. 14 Protocols framework

There are a large number of protocols currently in use that suit different simulation purposes. These frameworks also evolved out of development in the US military, but are now becoming the architecture standard. Of all the protocols, high level architecture (HLA) is rapidly becoming the most well-known support to distributed simulation activities. Before proceeding, and in order to describe HLA in more detail, it is imported to introduce certain terminologies. As was stated earlier, in simulations using HLA, an individual simulation is referred to as a 'federate'. A group of federates that is intended to interoperate with one another form a 'federation'. This terminology was introduced to avoid excessive use of the term 'simulation', where, in describing a simulation, it would become unclear whether one is referring to the individual or the whole.

HLA has two stated goals. The first is to achieve the interoperability of a broader range of types of simulation than previous protocols achieved. The second is to maximize the reuse of existing code and architecture framework. HLA is defined by three components: an interface specification, a set of rules and an object model template.

HLA interface specification: This defines the rules of federate interoperability via a common interface. The focus is on the mechanism of interoperability rather than on the content of communication. The interface specification is defined in terms of a number of services between the architecture implementation and the federates. 'Runtime infrastructure' is the name given to a software implementation of the interface specification.

HLA rules: These are a set of compliance rules used to ensure the proper integration of federates during federation execution. There are presently 10 HLA compliance rules, although these are regularly reviewed.

HLA object model template: This provides a standard framework for recording the information contained in the required HLA object model for each federation and federate.

5.7 Main advantages

Many software vendors, universities and consultancy companies have traditionally used a local simulation approach in a supply chain context. Only in recent years have some of the features of DS been recognised as having important benefits for enabling sound simulation models in support of SCM policies [13].

Parallel and distributed simulation ensures the possibility of realising complex simulation models which cross enterprise boundaries without any need to share local production system models and data; as previously discussed, companies that do not belong to the same enterprise might not be willing to share their data openly. [13] The PDS paradigm guarantees the ‘‘encapsulation’’ of different local models within one overall complex simulation system, so that, apart from the information exchanged, each model is self-contained.

PDS provides a connection between supply chain nodes that are geographically distributed throughout the globe, guaranteeing that each single simulation model is really linked to its respective industrial site. In some cases, the execution of a PDS model allows for the reduction of the time spent on simulation, since separated models run faster than a single complex model.

6 Conclusion

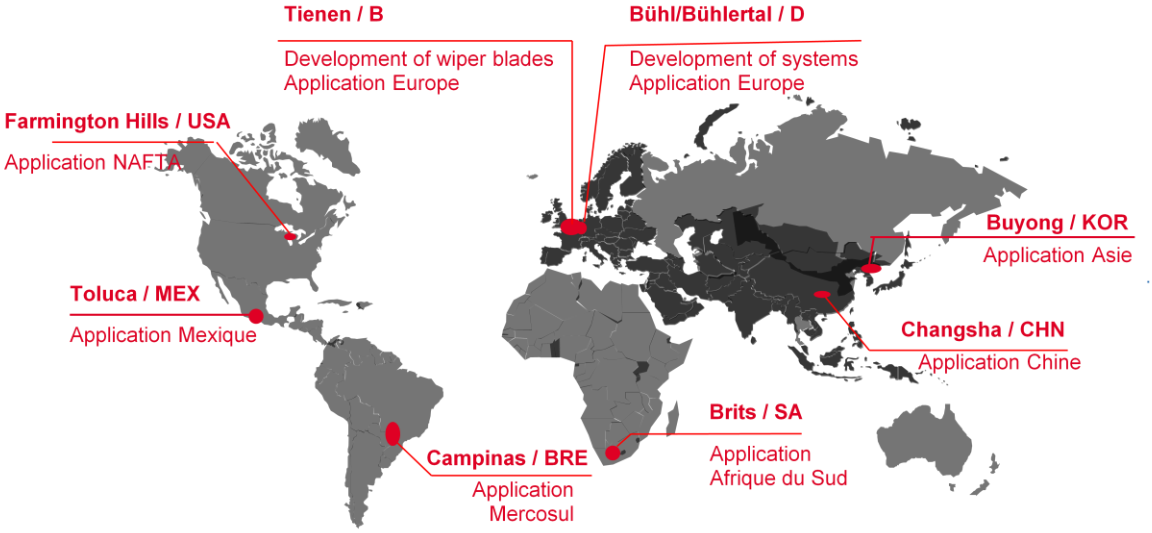

Fig. 15 Wiper-systems development locations

Modern industrial enterprises operate in a rapidly changing world, stressed by even more global competition, managing world-wide procurement and unforeseeable markets, supervising geographically distributed production plants, constantly searching for new products and high quality customer service.

The new goal of supply chain management in business is to create integration and generate an “agile” and multi-firm cooperative system, capable of exploiting profitable opportunities in a volatile market and promoting cooperation between component firms, while enhancing their autonomy and availability [16].

This natural evolution requires tools which are able to obtain an a priori estimate of the efficiency and effectiveness in a (SCM) context in terms of operational costs and customer service satisfaction. Therefore, the simulation use of the operational characteristics in (SCM) is a strategic tool which will allow the best management policies to be defined.

The local simulation paradigm is still the most often used, preferably within intra-company projects for verifying the feasibility of new solutions [13]. On the other hand, SCM typically requires independent enterprises to share information with each other. This problem is further exacerbated in geographically distributed networks. Complex products are very seldomly manufactured by only one company or in a single location. Usually, components are produced by different companies and assembled at different locations. The capacities of warehouses are reduced and parts are often delivered "just-in-time", which increases the dependency between companies. Therefore, it will become more important in future studies to create distributive simulation solutions.

In the development of wiper blade systems, BOSCH has several locations with different competences present in numerous countries. These manufacturing facilities cover diverse market manufacturing necessities and use expertise in broad domains of simulation, such as: numerical testing, analytic calculation and others stated in chapter 4. Simulation is used to test the general behaviour of the wiper blade at high speed, rubber, beams, water pull back, overspray and flip over noise.

Within these frameworks, individuals with particular model development expertise and tools were given the capability to create models or provide simulation services readily accessible to others, without requiring them to have additional knowledge outside of their traditional, domain specific tools [14].

Unlike local simulation (DS), this powerfully fulfils the previously stated requirements. With this approach, each simulation model can run in its own local environment, exchange data and generate synchronization, in order to ensure success.

This form of simulation has a broad range of applications; several simulation techniques can be used and defined according to the relevant scope and objectives. Specific simulation morphology can be built to the address different problems and to share distinct levels of ownership in specific projects. Also note that these simulation software processes may model something as large as factory or something as small as an individual piece of industrial machinery.

Generally distributed simulation models are able to solve some problems. To summarize, DS allows each federate of the federation to [3]:

- Hide any proprietary information in its implementation as needed
- Simulate multiple manufacturing systems at various degrees of abstraction
- Link simulation models developed using different simulation software
- Take advantage of additional computational power
- Offer simultaneous access simulation models executed for users in different locations
- Reuse of existing simulation models with little modification

6.2 Distributed simulation issues

Being an integral part of simulation, DS has some of the application issues stated in chapter 2. Although there is a case for experimenting with new technology, it is true to say that the same issues have acquired a role in DS with the development of HLA. Today’s simulation projects concentrate on the design or redesign of complex systems. They must often deal with complex system-control issues, which can lead to the development of problems concerning the system-control logic that is tested during the simulation. HLA, the main protocol used in DS, is now moving towards standardization, through each company's specific given use of each simulation's relevant purpose. Currently, every company developments of the protocol focus on a detailed interface specification. Developments in DS, notably in HLA, have significantly complicated data collection activities, due to the increased scale and diversity of federations. This problem is being addressed by a number of groups in the DS community, who have an active interest in data collection and analysis. Considering the particular impact of HLA, it is possible to break down the problem into the following four areas [15]:

- **Selection**: What are the actual requirements and therefore what do we want to collect?

- **Collection**: How do we collect the data we are after, or where is it?

- **Storage**: How do we store it?

- **Retrieval**: How do we get the data back and make use of it, where and when is it required?

6.3 Future and research opportunities

The rate of change in simulation technology has accelerated in recent years, and there is every reason to believe that it will continue its rapid growth and cross the bridge into mainstream acceptance. Simulation software has taken advantage of new operating systems to provide greater ease of use, particularly for first-time users. These new operating systems have also allowed for the greater integration of simulation with other packages (such as spreadsheets, databases, and word processors). It is now becoming possible to foresee the complete integration of simulation with other software packages that collect, store and analyze system data.

The internet and intranets have had a tremendous impact on the way organizations conduct their business. Information-sharing in real time is not only possible, but is becoming mandatory. Simulation tools are being developed to support distributed model-building, distributed processing and remote analysis of results [2].

The development of DS is far from over. The use of the HLA protocol itself is continually developing as lessons are learned from its previous applications. Consequently, a number of potential areas of research can be identified. The following is not an exhaustive discussion of such research, but is intended to emphasize a number of the dominant trends in the current literature:

Reliability: The reliability of DS does not appear to be an issue in its own right. This is perhaps due to the fact that the reliability of a simulation is not as crucial as the reliability of an actual system on which people depend, where generally there is a real-time constraint. There are, however, reliability issues raised in particular areas connected with DS. One such area concerns the reliability of techniques and algorithms. The reliability of the overall DS federation is addressed in HLA through the of the federation management group of services.

Verification and validation (V&V): Significant emphasis has been placed on the realism of the artificial environment. It is important to remember that it requires more than impressive graphics to ensure the benefit of applying DS technologies. The complexities of the DS environment represent a variety of challenges to existing methodologies and techniques for simulation model verification and validation. Consequently, there is ongoing research in this area.

Time management: This is a complex issue and is the key to the interoperability of federates, who may employ different time management schemes. There are numerous issues raised by research into time management and the progress of time in a DS environment.

Data collection: In general, there is some data collection activity associated with most systems, whereby data is collected to fulfil some predefined requirement for analysis. The analysis may be concerned with evaluating the performance or behaviour of the system's users, or concerned with the performance or reliability of the system itself. This is also true of DS. Data collection activity depends on the nature of the DS application and the requirements determined by the application managers.

It is possible to foresee that, in the future, even more specialized tools design will be developed for very specific environments, to respond to system activities that are unique to each simulation project. Some of these types of products are on the market today, in numerous applications. Soon, a set of enterprise-wide tools will be available in order to provide the ability for individual employees, throughout an organization, to obtain answers to critical and even routine questions in real time. With rapid advances being made in information technology (in both hardware and software), it is very difficult to predict much about the use of simulations in the distant future, but even now we are seeing the development and implementation of features in simulation software that can totally change our integrated production system.

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