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AN INDUSTRY PERSPECTIVE ON THE ROLE OF EQUIPMENT-BASED EARTHMOVING SIMULATION

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ABSTRACT

Over the last two decades, simulation of construction operations has gained momentum in its ability to provide solutions and understand complex problems. However, there still remains a distinct gap between its role in academia and industry. This gap is not necessarily due to the strategy – process interaction or activity scanning – but in the orientation towards application. The success of a simulation program lies in harnessing the collaborative features within a complex pattern of hierarchical levels and user groups. For this purpose, simulation is classified into macro and micro-level. User groups vary from manufacturer to supplier, and to the owner (contractor). The purpose varies from designing machines and components, to sales and customer-support, and to process design and improvement. The functions of a simulation program must facilitate decision-making for each user group that can be only achieved by the integration of micro- and macro-level simulation. In addition, the role of simulation will constantly evolve with the advent of emerging technologies. In this paper, the authors present a discussion on the role of simulation in e-commerce from the perspective of construction equipment industry.

1 INTRODUCTION

Almost all types of construction operations are characterized by uncertainties in duration and resource consumption, and dynamic interactions. Specifically, earthmoving operations, which are predominantly equipment based, are further defined by cyclical tasks. Hence, construction operations involving earthmoving equipment offer a fertile ground for the implementation of computer-based simulation. Therefore, it is no surprise that the early development of simulation of construction operations were focussed around earthmoving operations (Vanegas et al. 1993, Smith et al. 1995, Hajjar and AbouRizk 1996, Martinez 1998).

1.1 Requirements of a Simulation Program from an Industry Perspective

From a (industry) user's perspective, the primary role of simulation is assisting decision-making. The decisions could involve selection of equipment, estimation of parameters for future operations or understanding parameters for the improvement of ongoing operations. Key elements involved in the decision-making process are the user (interest) group, functionality, frequency of use, and user-interface. A trusted relationship (affiliation) with the party providing decision-supporting information is also an important factor. The success of any simulation program lies in the ability to answer the question – "who is going to use what, why and how often?"

In the earthmoving equipment industry, the user group varies from manufacturers, to suppliers (distributors) and to owners (contractors, sub-contractors). The manufacturer is interested in decisions involving the design of a single equipment - engine and transmission characteristics, drop box ratio, component life etc. On the other hand, the supplier is interested in decisions involving sale of equipment – owning and operating cost, fleet size, production, add-on options etc. The supplier also explores decisions involving improvement of ongoing operations (support team) – process design parameters such as over- or under-loading, position of equipment, design of haul roads etc. The owner is interested in all of the above decisions, some implicitly. Unless a simulation program is targeted for a particular user group, it should encompass most, if not all, of the above functionalities.

The design of a simulation program should be closely tied to the frequency of use. Consider the user group of manufacturers. They are constantly interested in fine tuning parameters and therefore, their frequency of use is high. The user group consisting of suppliers uses the simulation program to facilitate the buy or sell decision. Considering that one supplier works with several owners, the frequency of the use is high. The support team of the supplier uses a simulation program to make decisions on ongoing operations, which are case-based. Therefore, the frequency of use is not high. As for owners, the nature and the face of the job keeps changing constantly, unlike mining operations, which are substantially long-term operations. Therefore, a simulation program for construction operation is typically used once or twice during the life cycle of a project.

Another requirement of a simulation program is the simplicity of the user-interface. Except for the manufacturer, predominantly consisting of design engineers, the other user groups are interested in the "speed" of the solution rather than the "details" of the solution. For example, the supplier is interested in the what-if scenarios. The user-interface should consist of graphical elements which will facilitate a transaction within a short duration. Moreover, almost no user group, including the owner, has sufficient time to learn a custom-specific language or symbolic representation. Minimal training is a mandatory requirement for the successful implementation of a simulation program in the earthmoving industry wherein the literacy level of the workforce is modest and the turnover rate is high.

The most essential requirement of a simulation program from an industry viewpoint is the value provided through the incorporation of domain knowledge. Domain knowledge can be used as part of the user-interface to make the program idiot-proof. For example, a simple comparison of the dump height of the loader and truck height can advise the user if the selection of the equipment is appropriate. However, the incorporation of the domain knowledge within the simulation engine substantially increases its acceptance and use. For example, if a simulation of a haul truck going downhill detects that the continuous use of the retarder generates substantial heat, the value of using simulation is increased by an order of magnitude.

Having defined some critical requirements and success factors for a simulation program from an industry viewpoint, the next section traces the development of research on simulation in construction.

1.2 Simulation Programs in Construction

There are several articles which describe in detail the development of the body of knowledge on simulation in construction (McCahill and Bernhold 1993, Martinez and Ioannou 1999, Shi 1999). The intent of this section is not to reproduce a similar account but to emphasize the focus of development.

Martinez and Ioannou (1999) succinctly state that the scope, flexibility and suitability of a simulation program depend on its application breadth, modeling paradigm and flexibility. Unlike general productivity tools such as front office programs, simulation programs are very specific to a domain or an industry. For a simulation program to be successful in a domain, it needs to posses the correct balance between scope, flexibility and suitability.

One of the earliest simulation tools in construction is CYCLONE (Halpin 1977). CYCLONE provides a problem orient language (POL) to represent the abstract of a physical system through modeling elements. Programs such as CYCLONE, UM-CYCLONE (Ioannou 1990), STROBOSCOPE (Martinez 1996), SIMPHONY (Hajjar and AbouRizk 1999) are general-purpose simulation programs or environments capable of modeling non-construction systems as well. A general-purpose simulation tool offers the application breadth, which targets various domains. However, the suitability of such programs to any one domain (for example earthmoving) is limited. They serve as excellent candidates for teaching purpose where the intent is to teach concepts using wide-ranging applications.

The examples cited for general-purpose simulation programs are mostly based on activity scanning strategy. There are several industrial / manufacturing related general-purpose simulation programs which are based on the process interaction strategy. Interested readers are referred to Martinez and Ioannou (1999) and Shi (1999).

Special purpose simulators are designed to target a specific domain. For example, AP2Earth (Hajjar and AbouRizk 1996) and Earth-mover (Martinez 1998) specifically concentrate on earthmoving applications. The intent of special purpose simulators is to explore the depth of a domain. When the domain knowledge is relatively minimal, then the difference between general-purpose and special-purpose simulation programs become minimal. It is also important to point out that most special purpose simulators are based on general-purpose simulation programs and so, share the modeling paradigm.

A majority of the special purpose simulators use an intuitive user interface to translate a user's requirement into secondary computer code, which in turn is interpreted by a simulation engine. Most of the existing simulation programs (general purpose or special purpose) do not use domain knowledge as part of the interface or the simulation engine. The use of domain knowledge in the user interface makes a simulation program idiot-proof while the use of domain knowledge within the simulation engine makes it very applicable to that particular domain.

Animation using computer graphics is sometimes referred to as simulation. It is worth clarifying at this point that animation is a graphic representation of a fundamental simulation model. The value provided by animation is in validation and communication (Cor 1998, Shi and Zhang 1999).

It is interesting to observe the structure of mining industry in comparison to the construction industry from the viewpoint of simulation. Although fragmented, the different aspects of mining industry focus on specific operations and equipment. The open cast mining operations deal with trucks and loaders, the tunnel boring operations deal with tunnel boring machines (TBM) etc. The operation-oriented approach has resulted in special purpose simulators with domain knowledge embedded in them. For example, TALPAC `<http://www.runge.com/talpac>` focuses on loader truck operations and DRAGSIM `<http://www.runge.com/dragsim>` focuses on dragline operations.

From the ongoing discussion, it is clear that the most of the existing simulation programs in construction focus on a breadth of applications. This approach is well suited for academic teaching and research. However, the success factors for a simulation program for an industry are based on the ability to cover the depth of an application by incorporating the domain knowledge. The difference in the approach creates a gap between the academic and industrial efforts. This presents a big challenge in creating a synergy between academia and the industry.

2 EVALUATION OF SIMULATION PROGRAMS

The previous section reviewed the requirements of a simulation program from the industry viewpoint and a cross section of simulation program in construction. It is very difficult to evaluate a simulation program from a generic perspective. Considering that the earthmoving industry is further segmented based on the different user groups (manufacturer, supplier and owner), this section specifically illustrates the evaluation of simulation programs for one group – supplier. It is also worthwhile to point out that the supplier's role of equipment marketing and sales provides the best potential to illustrate the value of simulation.

The users define specifications and the functionalities of the simulation program. The performance measures for the simulation program at the highest level of hierarchy are the completeness in terms of the user's vision and ability to deliver and implement within the user's business. It is important to point out that these performance measures are driven by business objectives of the user and includes more than the criteria defined by Martinez and Ioannou (1999) – scope, flexibility and suitability of a simulation program. Figure 1 presents a graphical representation of six equipment-related earthmoving simulation programs. In order to remain unbiased, the names of the actual programs have been left out. The legend shows four industry-based tools in comparison to two academia-based tools. The sole intention of this classification is to show the place of birth of these programs.

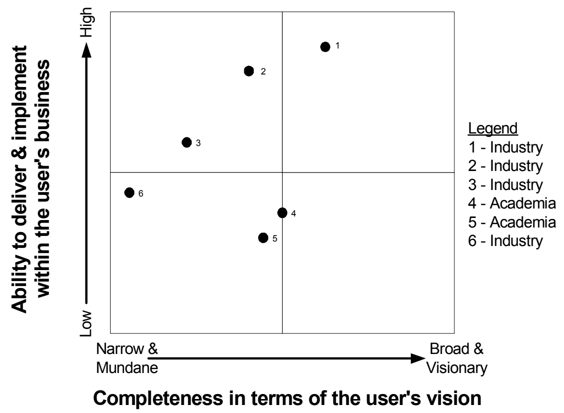

Figure 1: Overall Evaluation of Simulation Programs

Completeness in terms of the user's vision includes several elements such as functionality, user-interface, technology, reliability and integration, data security, and problem solving capability. The abscissa represents the ability of the owner of the simulation program to deliver and implement the program according to the user's vision. This measure also includes the ability to provide support and maintenance across an enterprise, provide a help desk for trouble shooting, and assist in training.

Figure 2 represents the next hierarchical level of evaluation wherein the programs are evaluated for individual characteristics. Functionality of a program represents the range of value-addition features such as modeling capability, database, deterministic and stochastic approaches, optimization etc. User-interface not only refers to graphical representation of screens but also on the use of the interface to elicit input in an intuitive manner. In addition, the incorporation of domain knowledge into the interface will add to the acceptance of the program. Technology represents the internal architecture of the program – if the program is object-oriented, object-based, web-enabled etc.

Reliability and integration are very important requirements for an enterprise. The user acceptance will be very low if the program is unreliable and crashes often. Simulation programs can be standalone or part of a front

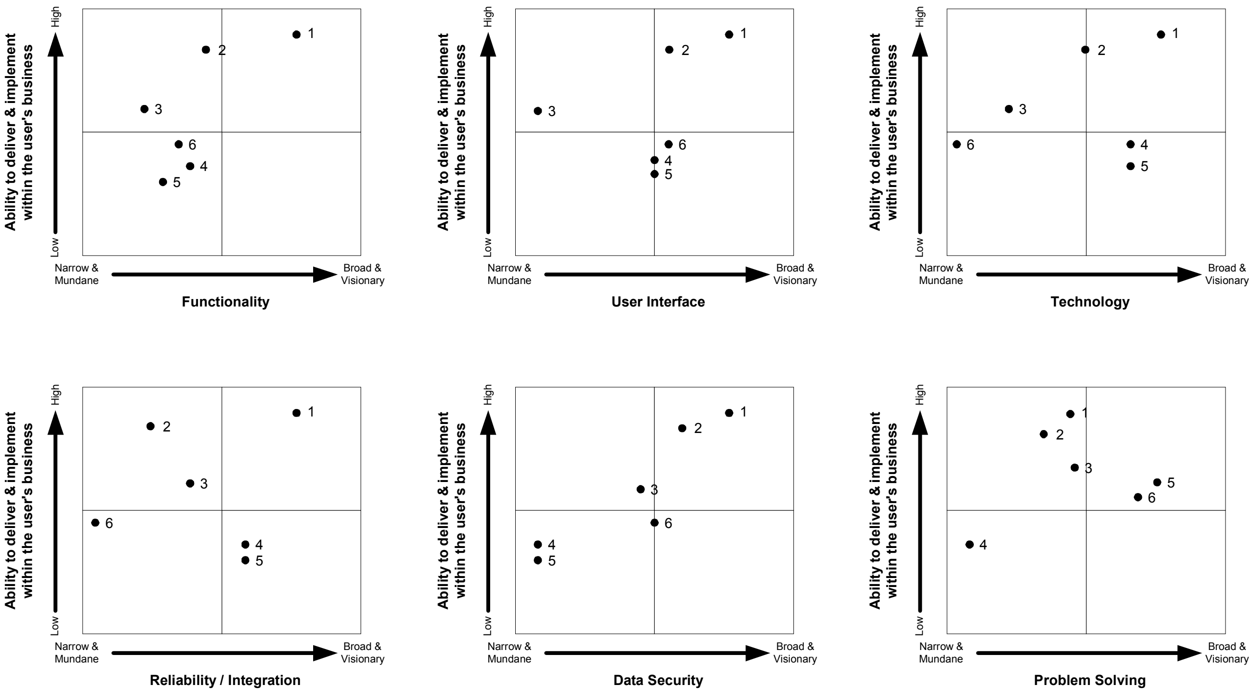

Figure 2: Evaluation of Individual Characteristics of Equipment-Related Earthmoving Simulation Program

office suite, in which case the program should have a good application interface to share data. One suggested implementation is the common object model (COM). A versatile simulation program should have the ability to separate the data from the process. The data referred to here refers to equipment specification, owning and operating cost etc. It should be possible to update and modify the data independent of the processes. Security of such data is of paramount importance because the output / recommendation of the simulation program is directly dependent on the input. The characteristic of problem solving refers to the feature of modeling intricate details of a complex environment, such as modeling no-passing haul road segments or one-way traffic haul segments.

The preliminary observation is that no single program performs well for all the characteristics. The other observation is that academia-based programs still lag behind the industry programs in terms of acceptance. On further introspection it appears that the industry-based programs are need driven while the academia-based programs are opportunity driven. It is not that academia-based programs lack the technology or the capability, on the contrary, academia-based programs have abundance of knowledge. The lack of efforts to transfer concepts to prototype and prototype to functional programs is the principal reason why the inertia for technology transfer between academia and the industry is subdued.

3 FRAMEWORK FOR MODELING AND SIMULATION

Based on the requirements and the evaluation of the simulation programs, a framework for modeling and simulation is developed for equipment-related earthmoving simulation programs. It is intended that this framework be used as a template for any other domain of choice. Three levels of modeling and simulation can be envisaged within a domain: micro-level (individual entity), macro-level (system) and meta-level (rules).

3.1 Micro-Level Simulation

Micro-level simulation refers to the modeling of the performance or the characteristics of individual entities. For example, in the earthmoving domain, micro-level simulation refers to the modeling of internal characteristics such as engine and transmission, travel time of a truck etc. Most of these characteristics are typically governed by equations. However, it is not possible to predict the final state knowing the initial state. In other words, knowing the starting position of a truck on the haul road is not sufficient to predict the travel to an end point. There are several parameters such as acceleration, speed, and rimpull which continuously change along the way. This situation requires a fixed-interval simulation rather than a discrete event simulation. Micro-level simulation assists in decisions involving equipment selection.

3.2 Macro-Level Simulation

Macro-level simulation refers to the modeling of a system of individual entities or equipment. For example, in the earthmoving domain, macro-level simulation refers to a fleet of trucks working in conjunction with a loader. The essential elements, which need to be represented, are uncertainties in duration and resource consumption, and dynamic interactions. Although simulation suits cyclical operations, the simulation program should also facilitate non-cyclical operations. Discrete event simulation – activity scanning or process interaction – facilitates the representation of system level abstraction. Macro-level simulation assists in decision involving fleet size, production and unit cost, process design etc.

3.3 Meta-Level Simulation

Meta-level simulation refers to the modeling of domain specific requirements through rules. The meta-level is very much related to the implementation. Some simulation programs are based on network elements while others are based on programming. Essentially, the meta-level rules assist in network-based simulation tools to incorporate "smarts" into the program. Interested readers are referred to Kannan and Martinez (1998).

Comparing this framework with the development of simulation in construction, one can observe that in the past efforts have been focussed on the macro-level simulation. Improved concepts in conjunction with emerging technologies have contributed to the development process. However, attention to the holistic approach and a focus on the needs of the industry have been sidelined. The emphasis on strategy or modeling paradigm has out shadowed critical requirements of application, purpose and value-addition of a simulation program. The success of a simulation program lies in harnessing and collaborating features of the hierarchical levels.

4 EMERGING TECHNOLOGIES AND SIMULATION

The functions of a simulation program, the implementation of improved concepts and user acceptance are a function of the standard cost benefit trade off found in most economic activities. While the fundamental mathematical basis of simulation has improved over the last twenty years, the real benefits from simulation have been achieved through the broad acceptance and use of this technology to solve day to day problems. For example, a foreman at a mine may use a simulator to determine the best truck assignments for the day. This is possible because of the continual increase in low cost computing power. This progress allowed software developers to build special purpose simulators for given domains with the reasonable expectation that the end user will have sufficient computing power to utilize the system. This gave rise to markets for special purpose simulators with simple and intuitive user interface.

Just as the rise of computing power (sometimes termed as Moore's law) gave rise to new simulation products and new business models, the rise in communication power can be expected to have a similar effect. The current large install base and continuing growth in adoption rates of new communications technologies such as the Internet, WAP, XML etc. will provide opportunities for totally new simulation products and services. The new communication standards and technology allow the projection of simulation functionality to a much wider audience. Users interested in only intermittent or one-off projects will be able to utilize robust domain-specific simulations at very low cost through a Web-based interface. A new category of software providers has already appeared in the form of the Application Service Provider (ASP). ASPs provide software functionality across the web and manage all security, disaster recovery, upgradation and integration issues for a single rental charge. This industry is currently focused on business management applications such as accounting, HRM, and ERP systems, however technical applications can be expected to follow soon. Some of the vendors of special purpose simulation products are experimenting with this new delivery technology.

The interesting aspect of applying the new technologies is much more than the gain in delivery and low maintenance cost. Simulation software can be expected to take on new roles and whole new business models. The prediction being made in this paper is that the most important future role of simulation will be in the realm of e-commerce.

5 ROLE OF SIMULATION IN E-COMMERCE

One of the important requirements of a simulation program, as pointed out earlier, is the ability to add value to the business process. Within the traditional framework, the value additions provided by simulation programs have directly (sales and marketing) or indirectly (customer support) contributed to commerce. As simulation programs evolve from problem solving tools to gateways of information, they will directly or indirectly transform the industry in at least three areas: disintermediation, navigation, and affiliation.

5.1 Disintermediation

Communications along with computing power forces the separation of the economies of things and economies of information resulting in the explosion of richness and reach (Evans and Wurster 2000). "Richness" is defined as the quality of the information as defined by the user and "Reach" is defined as the number of users who participate in the sharing of information. This explosion will result in the deconstruction of traditional business structures which include value chains, supply chains, organizations, and franchises. The process of leapfrogging certain segments of the value chain is sometimes referred to as disintermediation. It is expected that a simulation program will be an important tool in the disintermediation process.

In a traditional value chain (within the earthmoving equipment industry), the role of a dealership and salesmen was to provide rich information to the consumer but with a limited reach. A simulation program in the hands of a dealer salesman was merely a tool to compare different scenarios. Original Equipment Manufacturers (OEMs) provided supplemental information such as parts and price catalogs. It is possible to envisage a disintermediation process wherein a comprehensive simulation program with an integrated database of parts and price will forge a direct link between the OEM and the consumer. This disintermediation process is gradually becoming prevalent in the automobile industry and is already visible in the used equipment market. Construction equipment is a form of capital commodity and hence, the role of a simulation program, which can evaluate the economics of different scenarios, will become very important in the disintermediation process. It is possible that this disintermediation will force dealers to concentrate on a core activity such as parts and service and provide navigational assistance to the consumer. While disintermediation is the initial focus of the changing business model, it will soon be followed by reintermediation where new players interpose themselves into a transaction to add value for the customer and supplier. The most prominent players in this game will be the "Navigators."

5.2 Navigation

Navigators are intelligent agents which can provide tools that search through an array of choices so that the consumer can determine the best solution. A good example of a navigator is the Amazon.com website. Within the earthmoving domain, however, the task of searching through different choices is a little more difficult. It is not sufficient for OEMs to list their equipment and specification on a retail web site and expect customers to start ordering direct. An equipment purchase is a complex process and determining the value a particular equipment model will bring to the customer's business is dependent on many interrelated factors. The customer needs help in navigating through these factors. Traditionally, this has been the role of the distributors or dealers. OEMs supplied information and training to its distributors' sales representatives and they, in turn, provided guidance and advice to the prospective buyer. This information can now be provided direct to the buyer via the Internet but a facility is required to help the customer assess the performance of a particular specification in their specific scenario. Simulation with its ability to predict outcomes will be the fundamental tool that allows customers to navigate through the various options and make assessment of the value of various purchasing decisions. The affiliation of the simulation program to the customer's needs will be a critical factor in the navigation process.

5.3 Affiliation

Affiliation of a navigator can be defined as the closeness of the array of choices generated by the navigator to the customer's needs. Objectivity of data and customer affiliation are two important factors in the navigation process. Traditional marketing programs have unilaterally generated competitive information with a focus on the owner's advantage. From a customer's perspective, such type of information provides support but not clear roadmap of alternatives. For consumer goods, the Consumer Report is a good source of objective, brand-neutral data. Similar form of data is mandatory for a navigator such as a simulation program to attain customer satisfaction. It is here that academic institutions could play the vital role of custodian of objective data.

Customer affiliation is the necessity to provide the best possible solution to the customer, irrespective of the owner of such solutions. Some services which the customer could expect from a navigator are informing the customer of purchasing alternatives available from other suppliers; explaining why a premium feature is worth the money; and sharing unbiased information on product performance or customer satisfaction. A simulation program, with its roots in mathematical model, armed with brand-neutral data will play a pivotal role in delivering customer affiliation. Then, the simulation program and the web-site delivering the solution information with customer affiliation will be perceived as part of a 'trusted domain.'

6 CONCLUSION

The purpose of this paper is to present an industry's perspective on the role of equipment-related simulation within the earthmoving industry. Academic research has been the primary cradle for simulation programs in the past. Industry-uses of a simulation program rely on the value addition provided through decision making. Although this is a complementary approach, there still exists a gap between the role of a simulation program in academia and the industry. The principal reason for this gap is not necessarily due to the architecture of the programs (strategy, modeling paradigm) but in the orientation towards the application. Typically, academia has followed an opportunity driven model while the industry strives for the need-based model. Therefore, one of the essential requirements for the success of a simulation program in the industry is the ability to answer the question – "who is going to use what, why and how often?"

The paper set out by defining some requirements and success factors for a simulation program. A review of the progress of the body of knowledge was presented next. An evaluation of existing programs based on the requirement for a particular user group within the earthmoving industry was presented. This methodology and the evaluation can be used as a template for any other user group and in a way, for any software suite. Based on the requirements, a structural framework for a simulation program was presented. The concluding sections discussed the role of emerging technologies and the role of simulation in e-commerce.

Simulation with its ability to predict outcomes will be the fundamental tool which will allow the customers to assess the value of different decisions. In particular, simulation will play a key role in the evolution of the value chain of earthmoving equipment. On the other hand, simulation will also the assist the OEMs in several ways. For the customer to assess the various options available through simulation all relevant parameters must be entered into the simulation program. The customer must, in fact, disclose the various scenarios. If the simulation is run online, which it must do to capture the latest information, then the OEM's can collect the information entered by the customer and then accurately profile the specific customers needs. The OEM can determine the value of the equipment to the customer as well as determine precisely the relative value of competing suppliers and then price accordingly. It is here the role of Academia could be expanded to jointly work on developing scenarios and solutions through simulation in a more intense dialogue in selected need-driven cases. Thus establishing a non-OEM credibility and playing an active role in the 'trusted domain'.

Next generation simulation tools will evolve into business solution gateways. Instead of focusing on particular scenarios such as load, haul, dump and return, they will concentrate on a higher plane – the application. By asking relevant questions on the application, the simulation program will be able to suggest solutions such as the choice of equipment and competitive comparisons, fleet size, expected production; provide cash flow analysis by looking up OEM / dealer price pages, resale values from auction sites and interest rates from lenders; check on parts availability and provide online ordering capability; and finally, assist the user in scheduling preventative maintenance based on the schedule of simulated work load. In summary, the simulation program will evolve into a portal of the OEMs and its support organizations. Academic involvement will develop from case-based involvement to a more steady presence in the portal paradigm. Collaborative capabilities in a joined knowledge pool shared by customer, academia and OEM will better and faster contribute to optimal solutions.

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