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THE DEFINITION AND POTENTIAL ROLE OF SIMULATION WITHIN AN AEROSPACE COMPANY

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ABSTRACT

Simulation software has reached a technological level that provides high flexibility and integration capabilities necessary for product design, development and manufacturing efficiency. Within the manufacturing industry, this simulation potential has not been fully recognized, although it is now becoming a matter of interest through the documented benefits it has provided. This paper discusses the issues of simulation definition, selection and integration with both business systems and each other. This also discusses the practical difficulties a business would encounter in the development of a fully digital environment through simulation integration, and data management.

1 INTRODUCTION

The manufacturing industry has not fully realized the potential of simulation, and very few companies have adopted simulation with the commitment needed for success. Simulation software has reached a technological level that provides companies with the flexibility and integration capabilities necessary for development towards their own fully digital simulation environment. With relatively low investment costs and support from the simulation vendors this can be a reality.

Discrete-event simulation was known to be the dominate simulation type in use within business, until the mid 80's. The potential of discrete-event simulation to optimize the business practices by forecasting the running of a facility was recognized early on. To apply simulation to more detailed operations performed on the facility floor were not possible at this time. However different types of simulation software began to emerge due to the combination of new technological capabilities, such as accurate 3D visualization with the idea of using simulation for optimization of processes. This new simulation can be used to cover a product's lifecycle, from conceptual design, through predefining detailed manufacturing processes to the final product assembly without any physical application required. Industrial demand is now increasing due to the significant benefits of simulation become more widely known e.g. cost saving, more efficient processes, shorter lead times etc.

It has now become increasingly difficult to select software for specific applications, due to this new diversity of simulation. The application boundaries of these different simulation types are unclear, especially, in light of modular extensions to simulation software. These extensions are integrated to the basic simulation software to provide further capabilities in other specific areas. Many manufacturing companies have adopted a number of simulation types for a variety of applications. However these companies do not fully utilise simulation in terms the integration capability possible. Simulation integration has the potential to increase its effectiveness of use and subsequently lead to a fully digital environment.

In practical terms the integration focus' on the data transfer between these simulation types. The management of this integration is crucial to maintain data integrity and version control for effective running of this full digital environment.

This paper discusses the key issues relating to simulation definition, its areas use and how simulation must be managed within the business environment. Simulation selection and integration difficulties in product and process development are addressed presents a high level guide to developing a fully digital environment.

A thorough investigation was required to ensure that all development aspects relating to this full digital environment are justified. The data gathered from a variety of sources, lead to focusing on two main areas, design and manufacturing processes and simulation capabilities.

2 RESEARCH DATA COLLECTION AND METHODOLOGY

2.1 Data Collection

The data sources required, covered both tacit knowledge from simulation practitioners experiences and explicit data from vendors and companies published documents (BAe, MA&A 1997), (eManufacture Solutions). These provided simulation characteristics and its use for design and manufacture of airframes.

Initial data collection was based on a questionnaire aimed at simulation practitioners within industry, focusing on their simulation software options and their applications. This base information provide direction for a more detailed data collection through simulation vendor documentation and interviews with simulation practitioners. This provided simulation capabilities focusing on application distribution, simulation key functionalities offered, and simulation integration and management across different application areas. Documentation and staff interviews from a collaborative aerospace company, provided further detailed information for a business case study assessment of product life cycle practices and simulation applications within business involved in the aircraft lifecycle.

2.2 Methodology

The methodology process adopted needed to cover all aspects, which would be effected with the adoption of simulation. The questionnaire highlighted the use of simulation, but also the lack of utilization throughout the full product lifecycle. The main use of simulation was undoubtedly discrete-event simulation, with in most cases, the use of a few other simulation types. This follows the maturity of these different simulation types, were the new simulation types have not yet been fully recognized. The following comments provided by some of the business practitioners through the questionnaire, stresses the importance of adopting simulation:

> "Our organization is quickly realizing that simulation plays a major role in winning future contracts and reducing overall product costs".
>
> "There is much more emphasis on 'affordability than ever before, and simulation is a means of quantifying the improvements. We can't just throw more people at the problem, the way it used to be done, so the logical alternative is to digitally simulate the process to reduce risk associated with the change".

The potential for integration of these simulation types not even mentioned, suggesting that this area has not investigated.

The assessment process of simulation software may require the comparison of simulation software with a common function which can be applied to a specific business application, but different capabilities overall. This assessment would not be valid. To clarify these different simulation types, we needed to recognize the business applications and their specific applications to enable to develop of these simulation types effectively. The methodology applied follows:

'Business Processes' within an aerospace company were broken down further to a low level of detail to examine the complex interactions formed in the airframe development.

'Simulation' types were classified and each type was detailed in relation to inputs, outputs, functionality, benefits and limitations.

'Integration' data paths were generated from one simulation type to another, thus building up a network of interactions to complete a process activity.

'Mapping' simulation types to business processes were established to show requirement and whether integration of different simulation types is a possibility within the context of the business environment.

3 SIMULATION APPLICATIONS

Simulation diversity has developed through a requirement from business. If there are processes that can be enhanced by simulation, there is likely to be some development of simulation software to address these processes. The application areas were determined through an assessment of business processes within an aerospace company (ste), the application areas were used to perform a case study assessment by a detailed analyzes of the product lifecycle process documentation. This documentation was used to breakdown the application areas into detailed processes.

3.1 Business Processes

Within a manufacturing business, product design and manufacture is essentially made up of different business application areas. These areas are performed concurrently and interact with one another to form the product lifecycle (Cutkosky and Tenenbaum 1990). Each application area has a main application focus e.g. 'engineering definition', which is made up detailed processes. Each detailed process can interact with other detailed processes, producing a complex and concurrent network of business activities (Fielding 1999). These application areas and subsequent detailed processes identified can be associated to simulation. The application areas and definitions are shown in Table 1, these areas are specifically identified to the design, manufacture and assembly activities in the completion of an aircraft.

Table 1: Application areas through product lifecycle.

Application Area	Description
Product/assembly design	Formulation of product concept & product options for product requirements
Physical prototyping	Product modelling for definition and analysis of physical requirements
Tooling/equipment design	Tooling engineering for identification and development of tooling options
Product manufacturing	Design and engineering of manufacturing processes & detailed operations
Product assembly	Assembly planning of subassemblies and the full assembly for analysis
Human operations and tasks	Design and analysis of human operations for production activities
Machine/robotic programming	Design and evaluation of programming for production machinery
Facility planning	Planning and verification of facility layout and resource location
Facility system planning	Production system planning and evaluation of performance
Training	Work instructions for shop floor assembly, machining and maintenance

3.2 Simulation Definition

The creation of more efficient product design, manufacture and assembly processes and overall optimization of the facility layout and manufacturing system is the goal of all manufacturing businesses. The application areas (table 1) cover all these processes. These business areas provided a focus in determination of the simulation types, by associating the business application to the main function of the simulation software.

To validate these focus areas; current publications of simulation success stories from the aerospace/automotive industries (Price; Ryan 2000), were also investigated to ensure simulation capabilities have been applied within manufacturing industries. Table 2 shows the final simulation types and definitions created through this study. The uniqueness of each simulation type is defined by the way in which key functions are combined. Vendor simulation information was used for a functionality study to determine the key simulation functions of each proposed simulation type above. The study into the key functions was necessary for a more detailed validation exercise to enable the mapping of these commercial simulation types to specific applications within product design, manufacture and assembly.

These provided clear definitions between each simulation type. The key functions identified should not be confused with the features of simulation software. The classification of a particular simulation software may have other attributes that can be applied elsewhere, thus overlapping into another simulation type. The implications of this will be discussed later in this paper, but what it essentially means is the thirteen simulation types in Table 2 cover all simulation software available for design, manufacture and assembly processes. For the purpose of this research the simulation types will prove necessary to mapping to the processes of the case study aerospace company.

Table 2: Definition of simulation types

Simulation Name (Type)	Description
Conceptual Product Design	2D sketching and 3D modelling of the conceptual design, basic dimensioning and dynamics of full structure and sub-structures
Detailed Product Design	3D modelling of the detailed breakdown of the sub-structures into subassembliesand components (tooling design also created).
Tolerance Simulation	Tolerance fit analysis of both minor and major subassemblies for component assembly and manufacturing purposes.
Mechanical Simulation	Mechanical analysis of dynamic sub-assemblies. Structural analysis of parts and full surface product assembly.
Digital Mock-Up	3D visualisation of full product assembly with all internal complexity for internal fit and interference analysis of final assembly.
Ergonomic Product Simulation	Insertion of human models for ergonomic analysis of the full product assembly for in service use.
Machine Process Simulation	Machining operation planning and major collision detection of global workcell processes and programming of CNC machines.
Machine Tool Path Simulation	Detailed operational planning of the tool piece, its interaction with the component and programming of CNC machines.
Robotic Cell Simulation	Robotic manufacturing operation planning for machining, welding, painting operations and assembly tasks in manufacturing.
Assembly Sequence Simulation	Sequence of assembly for the product, and disassembly and reassembly (sequencing for maintenance).
Human Task simulation	Human movement modelling, task analysis and work station assessment for manufacturing activities .
Facility Layout Simulation	Facility layout design for spatial analysis of manufacturing facility and interference assessment of manufacturing objects.
Facility System Simulation	Simulation of manufacturing process flow, calculation of the overall throughput and identification of resources required.

4 INTEGRATION OF SIMULATION

Integration can be approached in two ways, the theoretical and practical implications. The theoretical and practical difference of integration must be defined to ensure this is understood:

- Theoretical integration concerns itself with the possibilities of utilizing the combined capabilities of different simulation types for business applications.
- Practical integration involves the data transfer and data integrity between these simulation types to allow these combinations to function properly.

4.1 Theoretical Possibilities

The simulation type combinations (or interactions) for business applications are recognized, but their contributions are not clear. The integration comes in the form of the flow of information as data, (whether graphical or numerical data). As stated earlier, business practices are concurrent and so the data flow is made concurrent. Take the application ‘facility systems planning’ for example, this could be seen to be solved by a single simulation type i.e. facility system simulation. The truth is, other simulation types create some of the data entered into this simulation type, and this is considered as a contribution to the final application completion.

Figure 1 is a simple example to demonstrate this scenario of different simulation types contributing to the final facility system planning. Each simulation type performs its own activity to complete an application, which produces output data needed to complete other applications throughout the business process.

Figure 1 shows the combination routes needed to accomplish the final application:

- Detailed product data is produced through the product design iteration process of mechanical, tolerance and assembly analysis techniques.
- Assembly sequencing analysis needs the product data and human task analysis to investigate the assembly sequence of the product on the shop floor.
- Machining analysis needs the product data to investigate both movements of machinery parts and complex tool-piece path operations for machine programs.
- Robotic analysis needs the product data to investigate shop floor robotics involving welding, riveting, painting and automated assembly operations.
- The final data transfer is from the above shop floor optimization activities; the cycle time output data is needed for global facility analysis and optimization.
- All the simulation activities have to be based on the latest data or the follow on analyses by other simulation types will be incorrect and out dated, even if the full analysis procedure is correct.

This example can applied to all the simulation types identified earlier, by following the data dependency of the simulation a larger integration diagram can be formed. A simple representation of this can be seen in Figure 2.

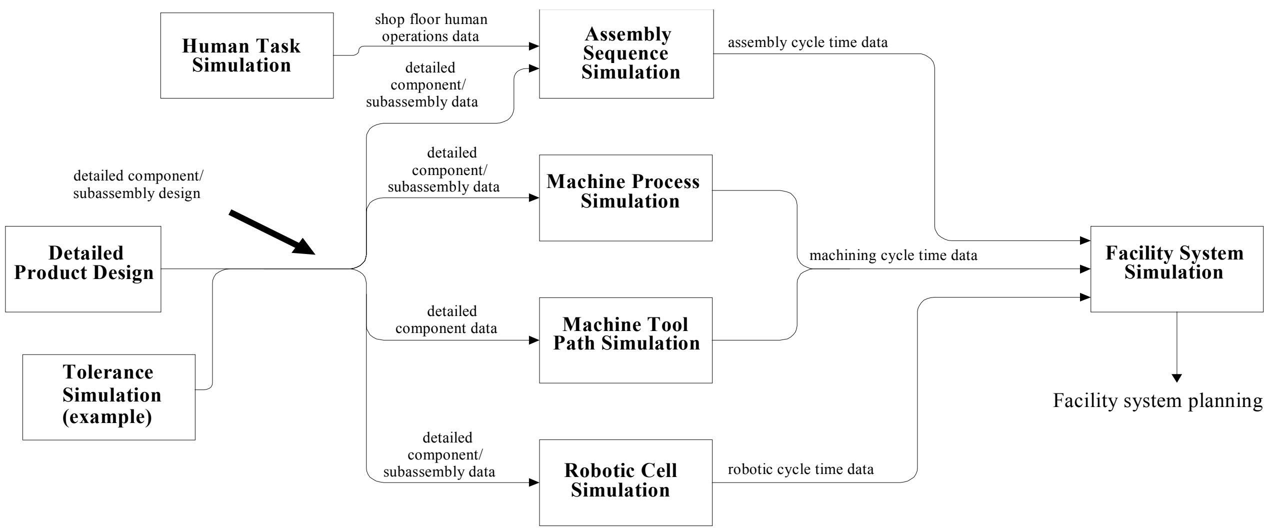

Figure 1: Data flow for application contributions

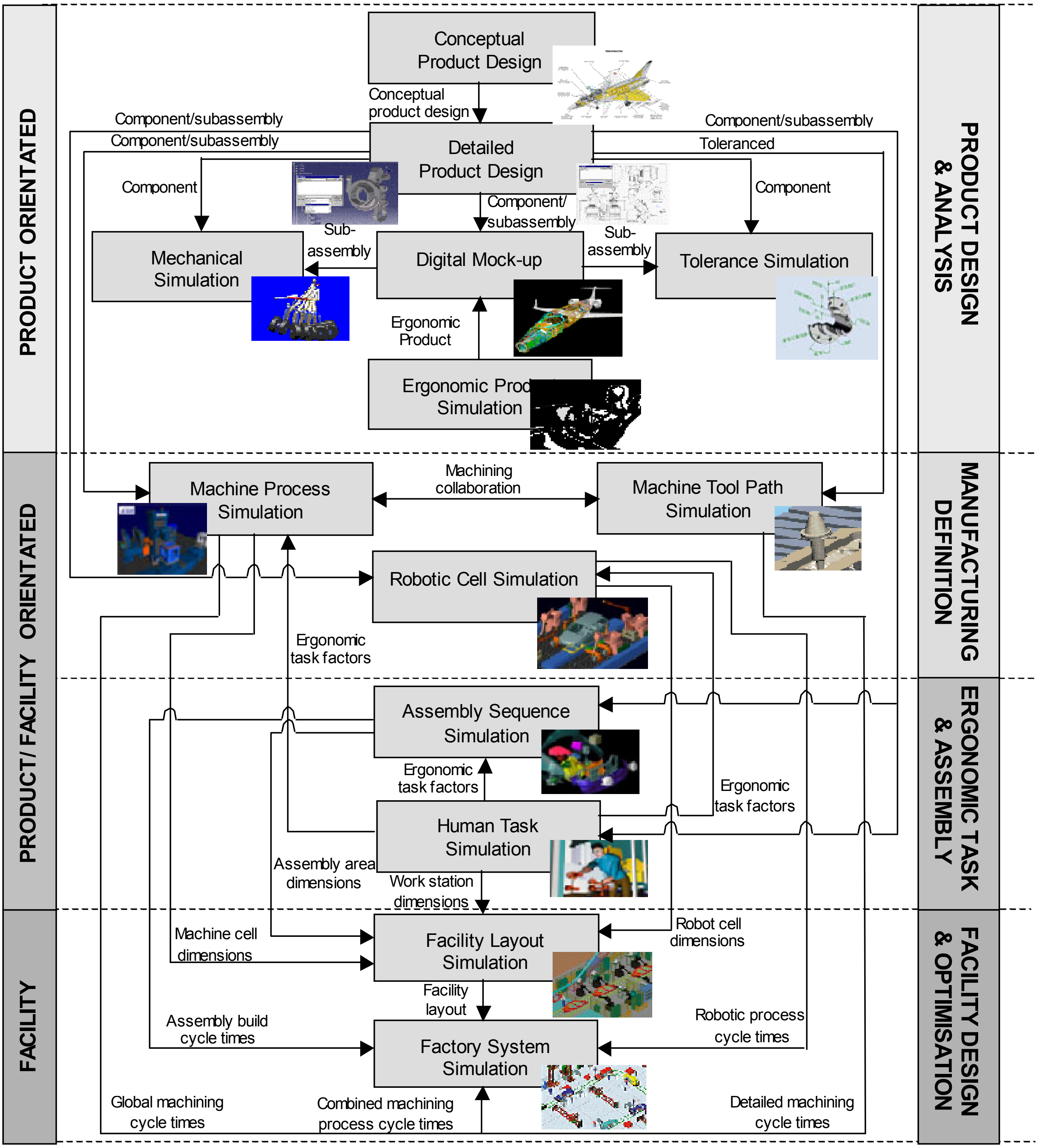

Figure 2: Simple diagram of simulation type links

4.2 Integration Levels

The idea of these interactions to form some seamless integrated single digital environment appears to be ideal for product design improvement and lean manufacturing practices (Hart; McLean 1993). Development of a simple hierarchical structure has been produced to demonstrate the full digital environment breakdown and intergration paths formed between all the simulation types. This is based on the high level categorisation and detailed interaction diagrams developed through this research.

Figure 3 shows the different areas of application that simulation can be applied. These areas differ in the iteration processes employed through these interactions:

4.2.1 Digital Prototyping

This is product orientated to provide an overall product design that will satisfy the detailed and technical product specification. The product must be designed in complex detail to represent the physical product, which will then be produced. The iteration between these simulation types has to be highly integrated, with detailed iteration processes of dimensional and mechanical analyses.

4.2.2 Digital Operations

This product data is not finalised, if taking into account shop floor considerations and in-service requirements. These requirements need to be investigated to ensure that the product design allows for efficient machining and assembly processes through 'off-line programming' and 'design for assembly'. This iteration process also has to be highly integrated in finalising the product design, due to the concurrent practices in product and process modification.

4.2.3 Digital Facility

The facility and manufacturing system needs to be designed to give the optimal system, based on the manufacturing processes developed from the product design. The placement of all entities needs for the facility and the movement of the product around the system will determine the overall facility layout and system throughput. The integration require the transfer of cycle time and workcell layout dimensional data produced from the digital operations.

Data exchange and data integrity are crucial elements in forming the single simulation environment and 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 use of different data formatting techniques, (data translators).

5 SIMULATION DATA MANAGEMENT

The question now is, would this single digital environment be of use, and would the problems encountered in implementation out weigh the benefits? The integration and management of this digital environment are important areas of concern, as the wrong approach will ensure failure (McLean and Leong 1997).

5.1 Practical Integration

Integration is solely based on data transfer (fig. 1 and 2):

- Transfer of product data - geometrical data (dimensional component/assembly characteristics)

Transfer of process data - numerical data (spreadsheets or Gantt charts of cycle times etc.)

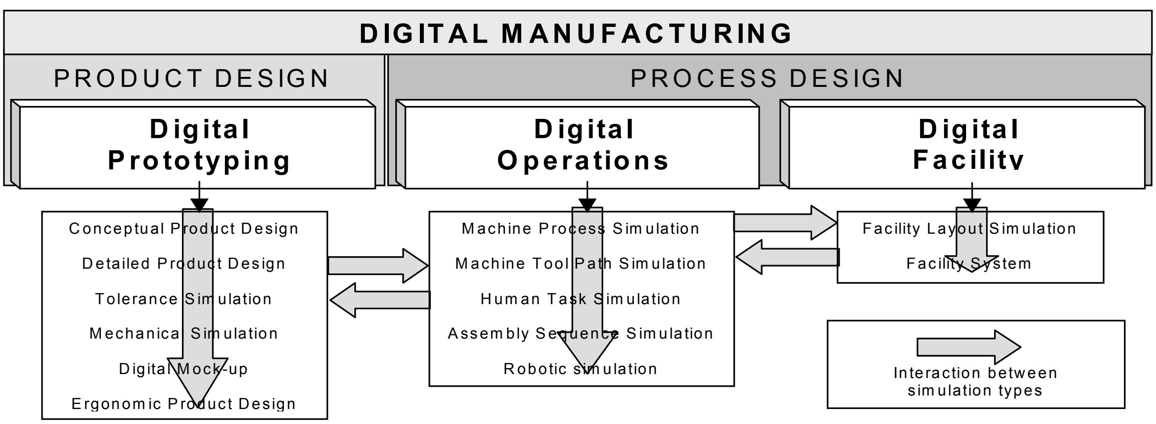

Figure 3: Hierarchical structure of interaction

5.1.1 Transfer of Product Data

Product data should be transferred using translators, which allow the data to be formatted and transferred as required. This means it carries across all attached data, for example, if subassembly data is transferred from CAD software to 'assembly sequence simulation' (a simulation category defined earlier). This subassembly must have its structural tree attached also, to allow for selection and manipulation of any part contained within that subassembly.

The practical difficulty is that simulation software has largely been incompatible and there were limited standardised data formats available, restricting the opportunity for data exchange. Neutral formatting of product data is now possible, with the emergence of IGES, DXF, STEP translators and various others. CAD software needs to be able to format the product data for transfer purposes. This may require an intermediate link between the CAD software and the simulation software to allow this exchange to take place. This intermediate link is a development of the integration capabilities of the CAD software, which can be used to transfer the product data to other software. The software receiving the product data e.g. simulation software, also needs to be able to accept this data as a function of its own integration capabilities. By building these integration capabilities into the simulation software, it also allows the transfer of data between one simulation type and another using the same neutral translators.

5.1.2 Transfer of Process Data

The numerical data that would be produced would appear in a much simpler form than graphical data. These data tables would only contain lists of times etc, of operations evaluated through simulation experimentation for example. Simulation software has been developed to allow integration to commercial spreadsheet packages e.g. Microsoft Excel etc. These data tables can be read in from these spreadsheets and manipulated to fit into the 'cells' of the simulation's internal spreadsheet. Due to the extensive commercial use of these spreadsheets, it may be more familiar to use these spreadsheets directly, by using simple programming to read it direct.

This process data can provide all the information simulation software may need, but the level of detail of this data may prove a problem. If the data tables are far too detailed for example, and only high-level cycle times are required, this data would need to be formatted before use. Calculations would need to be performed and presented in the right format to ensure it is the correct data needed, when it is read in, either to the internal spreadsheet or read in directly from a commercial spreadsheet.

This data transfer is made difficult due to the iteration processes performed, through design changes and business constraints. These need to be properly managed to ensure that up to data is used throughout the product life cycle.

5.2 Data Management

Integration is purely associated with data transfer and does not address the issue of data management. Concurrent manufacturing business practices has by nature, overlapping of application areas through the product development cycle, suggesting a close interaction of application areas. Each area has its own particular application, but this may also rely on the input from other areas to ensure accurate and precise results. As these application areas utilise simulation for its experimentation and analyses techniques this would also suggest that the simulation types adopted are used in a concurrent fashion as well. The need for data management is essential to maintain the progressive development of data from the various application areas and therefore from the various simulation types.

Direct data transfer between these concurrent simulation types would cause more problems than it would solve. With direct access to data from one simulation type to another, there are no guarantees that the data transferred across is the correct data to be used (finalised data required). Product data modifications and manufacturing process data iterations can be managed to highlight any changes by the implementation of control mechanisms through an intermediate database (Dassault Systemes). The intermediate database also allows easy and secure access to the required data without having to access local databases.

The data management system would have to manage a variety of data types in a number of key areas:

- Product (geometry, dimensional data etc.)
- Process (geometry, cycle time data etc.)
- Resource (process resource requirements)
- Facility (facility design etc.)

The advantage of this relationship is the immediate recognition and reaction to any alterations in these areas. For example, a product change that requires the alteration of a process step could in turn lead to more resources being needed, therefore a change of facility space and new set-up locations will be required. All these changes will be immediately flagged and the process and resource planners responsible notified. The functions will therefore have the opportunity to respond quickly, avoiding wasted capacity, delay and unnecessary costs. Data management is a necessary requirement for the successful integration of all designing, planning, and decision-making issues. For continuous development towards the optimal solution in product and process refinement, all functions need to able to respond directly to any changes necessary, leading to higher quality and productivity. Companies have started to develop this single digital environment with full data management systems to ensure the implementation and smooth running of simulation as a business system. There are a number of US companies that are leading the way toward reaching this goal, through full corporate invest, time and specific collaboration partnerships with simulation vendors in.

6 SIMULATION MAPPING

The simulation type key functions can be associated back to the detailed applications of each area. Table 3 shows this high level association, but this has been based on a detailed association analysis.

The overall spread of simulation across the applications areas provided two key trends:

- All simulation types have more than one application. The spread of the simulation types across application areas shows that due to the key functions of each simulation type, there is potential to apply a particular simulation type to a number of associated areas within the product life cycle (concurrent interactions).
- All the application areas can utilize a number of simulation types. An application area has a number of detailed applications that need to be performed, these applications run sequentially for development of the overall application area focus. Through this development there is the potential to utilize the use of simulation.

The reason for the latter point can be due to an application requiring a more detailed inclusion of different aspect of simulation. An example of this can be for the assessment of shop floor assembly processes. 'Assembly sequence simulation' can be used to design the assembly and develop the build sequence for the product by combining its own functions. In the case of two simulation types combining their own individual functions ('assembly sequence simulation' and 'human task simulation'), to complete detailed applications, such as shop floor assembly and maintenance processes which require human factors to be taken into account for health, safety and time for completion issues. The relationship between the simulation types, functions and their contributions in the completion of a particular application is not clear though. However it is important to understand this simulation network to progress towards multiple simulation use across the product lifecycle (Tseng, 1998).

7 CONCLUSION

Simulation is used to design and experiment on any number of scenarios that are refined before being put into physical practices within a business environment. The applications of emerging and diverse simulation types can help to enhance and analysis all aspects of design and manufacture of a product. However simulation use is very limited, because companies are not aware of, or are not convinced of the benefits simulation can provide, thus it is not used to its full potential. This paper highlights areas of discussion required for simulation development within an aerospace company:

- highlights the difficulties of simulation selection and to propose a basic simulation classification structure.

show the possibilities for theoretical integration of simulation types through data exchange to able the creation of a single digital environment

Table 3: Simulation use within business applications

	Simulation Types									
Application Areas	Product/assembly design	Physical prototyping	Tooling/equipment design	Product manufacturing	Product assembly	Human operations and tasks	Machine/robotic programming	Facility planning	Facility system planning	Training
Conceptual Product Design	•				•					
Detailed Product Design	•		•		•					
Tolerance Simulation	•	•		•	•					
Mechanical Simulation		•								
Digital Mock-up		•								
Ergonomic Product Design		•				•				
Assembly Sequence Simulation		•	•		•					•
Human Task Simulation		•	•			•				•
Machine Tool Path Simulation				•			•			
Machine Process Simulation			•	•			•			•
Robotic Cell Simulation			•	•			•			•
Plant Layout Simulation								•	•	
Factory System Simulation								•	•	

- highlight the practical issues of integration and data management in the implementation of this single digital environment

The truth is simulation is now being, not only recognised as a major benefit to many companies, it will become essential for a manufacturing industry to utilise simulation to remain competitive in light of the current technological advancements.

For a business to succeed in the use of simulation and ultimately create the fully digital environment, these issues must be addressed in detail before simulation can reduce time and cost, and increase quality and productivity in the design, development and manufacture of products. Only a hand full of companies have planned in detail their approach to simulation to gain the full benefits simulation can provide from identification of design errors earlier in the product life cycle to overall optimization of facility processes in the full development of products and processes.

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