TOWARDS COMPOSABLE SIMULATION: SUPPORTING THE DESIGN OF ENGINE ASSEMBLY LINES

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Abstract: This paper introduces the latest collaborative project work being carried out by Consultants at Lanner Group and Manufacturing Engineers at Ford Motor Company's PowerTrain Operations. The work involves aiding the design and optimisation of planned Engine Assembly Lines, by generating and experimenting with a complete simulation model produced using a spreadsheet interface, re-using and adapting a constantly evolving portfolio of modelling components. Such a methodology can be used to enhance quality and consistency in a process of continuous model validation and verification by using tried and tested building blocks. The re-use of modelling components, or 'modules', also helps to control and reduce model build time, a factor increasing in importance as automotive manufacturers strive to constantly reduce overall lead time and cost-to-market. The ease of use of the spreadsheet interface, coupled with the enhanced efficiency inherent in a modular approach to simulation modelling, empowers specialists and non-specialists alike to meet targets when designing and implementing complex processes. Modular Simulation is contributing to improved Business Process Management at Ford PowerTrain – improvements that, at the time of writing, are being rolled out globally.

keywords: Automotive, Business Process Management, Composable Simulation, Methodology, Reuse.

1. INTRODUCTION

This paper introduces the latest collaborative project work being carried out by Lanner Group Consultants and Manufacturing Engineers at Ford's PowerTrain Operations (PTO). A unique feature of the on-going consulting relationship between Lanner Group and Ford PTO is the reuse of a constantly evolving suite of modelling components, or 'modules'. Simulations composed using this portfolio of modules via a spreadsheet based front-end, have the advantages of being quicker, less costly to construct and maintain and easier to validate with a greater degree of confidence, as well as being more accessible to the engineers employed in the design and implementation of assembly lines.

After first giving a brief introduction to simulation at Ford PTO and their relationship with Lanner Group, this paper will explore some of the arguments surrounding Composable Simulation that have been put forward in recent years. The methodology enabling successful implementation of Composable Simulation will then be detailed. Finally, concluding remarks and potential future directions will be given.

1.1. Background

Ford PTO has used simulation for over 20 years. In that time, significant progress has been made, not only into the process design issues themselves but in the simulation methodology employed to make these improvements. Ford are using the latest technology developed by Lanner Group, a UK based specialist Simulation company. Their WITNESS simulation system is used by Ford throughout the world to model new and changing facilities in order to answer such questions as "What is the throughput achievable for a line?" and "How large should a buffer storage area be?"

The choice of tools, support and expertise deployed, have been the focus of a continuous drive to raise the awareness of, and thus utilization by, non-'simulationists'. [Ladbrook, 2001]. Another key area is that of increasing the availability of these resources to *all* at Ford PTO able to benefit from them. Several systems have been developed enabling simulation

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models to be created automatically via spreadsheet entry by Ford engineers. This effectively makes the simulation model easier to construct for an engineer, by using an interface that explains the data required from them in the form that is most readily understood. The input of simple data, indicating operation dimensions, in the spreadsheet places the next operation in the assembly line relative to the current operation. An entire production loop is created automatically by input of the data into a WITNESS model shell, the whole process being controlled by Visual Basic (for Applications) and WITNESS' own command language; creating a model dynamically and visually in real- time.

1.2. A New Assembly Line

The latest project work undertaken by the Lanner Group in collaboration with Ford PTO concerns the design and implementation of a new engine assembly line. One of the chief concerns of the work was to drive down the time taken to achieve successive levels of model development. Ford PTO comprises a subset of the complex interlinked and *interdependent* processes of Ford's Supply Chain. Timely decision making is thus required by Ford PTO to ensure they meet their commitments to Ford as a whole, who in turn are constantly striving to reduce time-to-market. Some have referred to this high level of interdependence as a 'House of Cards'.

Many of the building blocks that comprise this new line, or rather, a potential model of this new line, already existed. Much of the project thus comprised the adaptation of these modules to incorporate new production philosophies, and to ensure their continued interoperability throughout. In the following section we will discuss Composable Simulation with particular reference to this project. We will then detail the methodology followed by developers at Lanner and at Ford, and the steps followed by manufacturing engineers at Ford when building subsequent models.

2. COMPOSABLE SIMULATION

Composable Simulation can be considered a subset of the wider field of software reuse, a field with some considerable effort devoted to it: *"The software community has struggled with the concept of reuse for many years. Components offer a useful mechanism to support reuse. But a number of questions are raised by them as well".* [Page and Opper, 1999]. Ray J. Paul, in his foreword to Ezran et al. (2002), gives his approach to the reuse of programming and modelling constructs in this wider software/information systems context: *"To make the model provide future software reuse, sub-models of the organisation would have to be determined, made relatively self contained, represent a recognisable part of the organisation, and be likely to be required as part of some future unknown system. Quite a tall order."* This paper will go on to detail an ongoing string of projects satisfying this demanding brief.

So what exactly is Composable Simulation? *"Composability is still a frontier subject in Modelling and Simulation"* [Kasputis and Ng, 2000]. In such a new field it is hard to find succinct definitions (even more mature fields, such as OR as a whole, struggle with this!). At a high level it could be considered: *"…a system with which simulations are created at runtime to meet the specific requirements of that run. The user specifies his needs to a system that in real time builds a simulation…"* [Kasputis and Ng, 2000]. At a lower, software/model developer oriented level, Composable Simulation involves the selection of a series of existing modelling constructs, bringing them together in such a way as to model the real world situation at hand, in much the same way as existing modelling methodologies – but with much of the underlying coding already carried out. The literature in the area suggests that Composable Simulation represents something of a panacea. Why?

2.1. Time and Money Benefits

Much of the case for Composable Simulation is inherently intuitive, especially given the relative lack of published experience in the area: *"Intuitively, component-oriented design offers a reduction in the complexity of system construction by enabling the designer to reuse appropriate components without having to reinvent them."* [Page and Opper, 1999]. This time saving, particularly in the commercial context, has clear cost implications by potentially reducing the effort required to reach a comparable level of development of a simulation model sooner: *"Such a system offers the potential for providing higher quality simulations in less time for lower costs."* [Kasputis and Ng, 2000]. So, we see that not all of this benefit need be taken in the form of reduced costs, nor perhaps should it be…

2.2. Quality Benefits

On the issue of *quality* in simulations, there is little disagreement over the need to conduct VV&T (Validation, Verification and Testing) throughout the life-cycle of a simulation project [Balci, 1994], [Robinson, 1999] but: *"Assessing credibility throughout the life-cycle of a simulation study is an* *onerous task"* [Balci, 1994]. The case for improved quality is not equally valid [sic.] across the VV&T board though; where composable simulation really contributes is in the area of Verification ('building the model right') as opposed to Validation ('building the right model'). This is achieved, effectively, by extending the testing phase of successive studies – reused modules have already undergone some verification and testing in their previous role. Some verification is still carried out of course, as the more tacit/emergent properties of a module, and its relationship to models built, are experienced.

2.3. Ease-of-Use and Accessibility.

Another benefit of Composable Simulation is that afforded by the potential level of abstraction by the end-user, from the underlying code generating the behaviour they (wish to) observe. The division of labour so prevalent in just about any efficiently carried out enterprise is promoted by this abstraction, allowing a greater degree of separation of programming, modelling and, in the case of Ford PTO, engineering expertise. This promotes the efficient resolution of the real-world problem and allows the benefits of simulation to be brought to a far wider range of real-world problems, *and people*.

2.4. Difficulties and Reservations

Of course, what we have discussed herein is the *potential* of Composable Simulation to aid and promote the application of simulation, not the *actual*: *"Current capability in composability is limited"* [Kasputis and Ng, 2000].

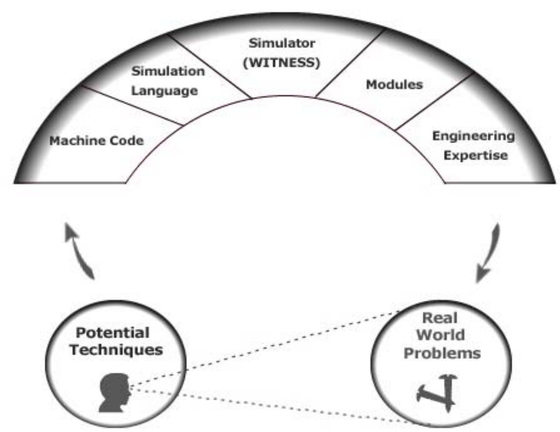
One of the key issues that may delay the adoption of component-based approaches is the potential complexity of their application: *"As the number of candidates for reuse (composition) becomes large, the benefits of reuse (composition) become negated by the costs of storage, organisation and retrieval of candidates."* [Page and Opper, 1999]. The authors go on to discuss the complexity of the selection of components. A non-technical summary is perhaps most succinctly achieved with the observation that for n components, there are in the order of 2^n possible models that can be constructed from them – any search for the 'optimal' combination could thus not be carried out in 'reasonable' (i.e. not increasing exponentially with n) time.

The issues facing the modeller, given a virtually unlimited choice of components, is similar to that faced by the researcher looking for information in the internet age. There is then a further complication caused by the need to establish the suitability of candidates – a factor exacerbated by the emergent properties of combinations.

2.5. The Overall Case

Much of the argument in favour of Composable Simulation here is of course analogous to the creation and subsequent uptake of simulators (i.e. simulation software packages such as WITNESS), as distinct from simulation programming languages. In the Composable Simulation arena, however, it is possible for the Consultant/Model Developer to bridge the gap *even further* between real-world problems and the techniques brought to bear upon them – using Modules:

Fig 1. Problem and Solution; Bridging the Gap.



The Consultant/Model Developer must become adept not only in the relevant software and modelling process, but also in abstracting from their work that which can be more widely applied *in a formal manner* – that is, generating Modules. We thus have a strong case for the greater specialisation of simulation Consultants in specific industry areas.

2.6. Moving Forward

Although in the long term, the suite of Modules could support both a span of domains and a range of granularity, the difficulty of this task is widely acknowledged [Kasputis and Ng, 2000], [Page and Opper, 1999]. Despite this, the desirability of this outcome is clear: *"In this envisioned future, simulation becomes ubiquitous."* [Page and Opper, 1999]. A pragmatic approach, suggesting how progress towards Composable Simulation may be made, has been given by Kasputis and Ng. (2000): *"Initial work… should deal with physical descriptions. Lessons learned in structures and* *processes can then be applied to the modelling of other aspects as they mature. It is also wise to limit the initial effort to one or a few domain areas or classes of applications."*

Finally; is it not simply good general programming practice to make use of existing routines and modelling constructs, where they exist and are available to the current developer or modeller? The answer is, of course, "Yes" - The factor that separates Composable Simulation from simple good practice is that reuse of the components is a design influence from the start. It is not simply good fortune that pre-existing components exist, these constructs were developed with attention paid not only to their current purpose, but likely future use too. Indeed, the fact that modules are designed with the current purpose in mind at all is merely a result of the setting of the work – commercial necessity being *"the mother of invention"*. The on-going Consulting relationship between Ford PTO and Lanner Group enables modelling to build upon previous effort, using a portfolio of modules and a tool to draw them together and construct the model. 'FAST' is just such a tool...

3. THE FORD ASSEMBLY SIMULATION TOOL (FAST)

Ford PTO are looking to apply a consistent global approach to Business Process design. The process about to be outlined, along with the technological tools and expertise required for its successful implementation, are being rolled out globally. Hand-crafting models from the start is difficult and time consuming, whereas reusing entire models is dangerous and unlikely to result in a valid model. FAST building however, takes seconds on a laptop computer, allowing the focus to remain on the issue of validity.

3.1. The Model Building Process

Developers, Consultants and Manufacturing Engineers all contribute to the finished model. Developers bridge the gap from programming to simulators. In the Composable Simulation case, Consultants/ Model Developers then build upon this by concentrating on building modules. Finally, the end-user inputs their requirements in a format tailored to their requirements, using the technology to solve the process design issues they are faced with.

3.1.1. The Developer

Developers provide the software, in this case WITNESS. Simulation packages, or simulators, require a difficult balance to be reached between flexibility and ease-of-use; a balance for which WITNESS has been recognized as a class-leader, particularly where complex and large-scale modelling is required. [Hlupic and Paul, 1999]

3.1.2. The Consultant

Generally, it is the role of the consultant to create the model itself, delivering the finished product with appropriate documentation. In this case, to a certain extent, Consultants /Model Developers step back from this position, instead concentrating on work intended to bring the model building exercise within reach of a wide selection of users, e.g. Manufacturing Engineers. This comprises liaising with Ford PTO to establish required new functionality whilst ensuring inter-operability, and requires the consultant to take a more abstract approach than building the model directly - focusing efforts on the underlying modules, and the WITNESS code that brings them together to form the possible models to be built at run-time.

3.1.3. The Manufacturing Engineer.

It is at the Ford PTO end that requirements are formulated in terms of module and FAST shell capability - FAST is the WITNESS 'model' acting as canvas on which the model can automatically be built. Much of the VV&T effort is focussed here, with recent developments by consultants being put through their paces. A benchmark of expected overall line performance has built up over the years, and so relatively tight upper and lower bounds of expected performance can be used for black-box validation of any assembly line not already in service. At a lower level, white-box validation is carried out by those who are most familiar with the processes being simulated, although this is usually done by those also adept with the WITNESS software. Finally of course, building, running and experimenting are all carried out at run-time. Clearly, with such easily modified model structure, scenarios can be investigated with ease.

3.2. Challenges Faced.

The greater degree of abstraction from the finished simulation model presents the Consultant/Model Developer with particular challenges to overcome. Many of these were alluded to in the previous section, but are discussed here with particular relevance to the Engine Assembly Line project. In order to take account of new production procedures and philosophies, as well as build upon overall functionality, modules constantly need to be updated. The process of updating a module is itself relatively easy, taking in the order of hours rather than days. These modules are a popular and often used feature of the WITNESS simulation software. This project however, also had to find ways of assembling these modules automatically at run-time, and in almost any conceivable permutation. The challenge here, then, is the assurance of inter-operability.

To take a very simple and frequently occurring example, modules, when loaded into the FAST shell, must be placed relative to the previous module. The varying 'footprints' of these modules must therefore be taken into account when assigning a location for the new module to be loaded onto. Ensuring the correct display of modules, given the number of module types, is not a trivial task. The precise position of a module is a relatively unimportant feature when it comes to the correct functioning of the model – it is more useful for subsequent analysis and communication. It is also easy to see when this form of interoperability has not been achieved – it is readily seen on the screen. Much of the rest of the functionality of the module is both more important, and less easily spotted. It is important then to take a highly incremental, methodical and organised approach, incorporating frequent testing, to building new functionality – especially where new features are replicated across the entire model.

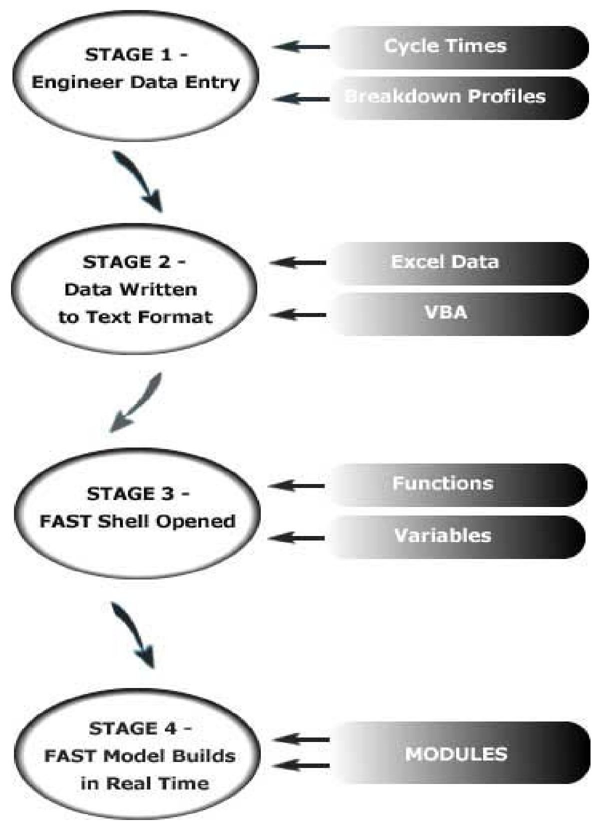
A specific new feature of the current suite of modules is the modelling of human behaviour. This is in its earliest stages, modelling certain features of human interaction with the production lines as a type of breakdown, according to an empirically defined schedule. Additionally, the model needs to keep pace with constant design changes in an iterative process of design → model → test → design. This is greatly assisted by the FAST build procedure; changes effected by Consultants/Model Developers at the modular level are automatically incorporated into all relevant parts of the model at run-time! Indeed, the potential for a Composable Simulation framework to accomplish this speed of development had already been identified: *"…there is a high probability that most or all of the representations needed for a new operation type would already exist. Therefore, simulations that operate within a composable framework would have the potential to adapt quickly to emergent operations."* [Kasputis and Ng, 2000].

The development time for new simulations, though greatly reduced, is still significant. New functionality, as well as production philosophies and procedures, create a moving target to the modeller – flexibility creates speed, and speed enables the design process to go through more iterations!

4. CONCLUSIONS

In many ways the advances made by FAST are an extension of modern simulation packages, where users are presented with a palette of iconic components [Page and Opper, 1999]. But FAST is a highly specialised extension of one of these packages, made possible by the high degree of flexibility in the WITNESS package. Because models can quickly be constructed and altered, building a model just prior to run-time to address specific issues, FAST *does* constitute a genuine move towards Composable Simulation. The status of FAST built models as Composable Simulations can be seen from the following diagram – modelling components required to create the model are not drawn together until run time, and this stage is automated according to the prior input of the Manufacturing Engineer:

Fig 2. Model Creation.



We saw in the previous section a number of reservations concerning the potential practical application of Composable Simulation. However, by restricting ourselves to a specific (engine assembly) domain, with a 'natural' and consistent level of modular detail, significant progress has been made through the control of combinatorial complexity. In this application we have therefore managed to achieve many of the benefits associated with Composable Simulation, and learnt valuable lessons that will be required if we wish to extend our modelling scope or broaden the problem domain.

5. THE FUTURE

Another frontier area in simulation is the incorporation of Virtual Reality [Waller and Ladbrook, 2002]. This has the primary benefit of communicating simulation to the widest range of agents. However, VR currently requires highly intensive work, both in terms of computation and development effort. A composable approach allows the consolidation of work already carried out, again helping to control the new effort required in each new endeavour – enabling those involved to stay ahead of each new leap in computational speed.

Going back to Composable Simulation *per se*, Web-based simulation appears to mark the envisaged culmination of this work – where modelling constructs proliferate in the same way that information does today. [Page and Opper, 1999]. There are special challenges here though, as the user doesn't merely need to search for the right constructs, but must take account of the relationship of the emergent properties of these components with the modelling objectives they face – as we have had to do with FAST.

We will thus always need a modeller – but their role may become more abstract. Today's modellers need not have in depth programming knowledge (although many of them do!), and the number of layers between the underlying code and the finished model grows. This frees up resources and enables those engaged in the activity of simulation to concentrate on the *modelling* of process, rather than the *coding* required to do so.

There exists between the Lanner Group and Ford PTO a continuing commitment to develop improved tools and methodology. By operating at the frontiers of current simulation expertise, continuous improvements have been made in the design, implementation and overall management of new and existing Business Processes at Ford – improvements that at the time of writing are being rolled out globally.

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