

# HOLISTIC DESIGN ANALYSIS

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**Abstract:** Systems engineering design analyses employed to assess time-dependent processes are invariably supported by fragmented simulation modelling tools. Mapping the data used can remove the fragmentation that exists between different engineering data sets. The data mapping approach explained herein will allow appropriate models to be either constructed or selected, which ensures good data connectivity between whatever analytical processes are employed. Within simulation models the formulae and equations use a number of parameters and variables. This research investigates the tools and methods that use those parameters and variables relevant to product effectiveness and worth, for the purpose of identifying an appropriate data mapping approach for holistic systems modelling.

**Keywords:** Simulation, Modelling, And Holistic Design

## INTRODUCTION

Within industry, many modelling tools are employed to help answer the question: Which system design is the most appropriate to a customer's fit, form and function requirements? In Defence the operational system design engineers employ operational analysis oriented simulation-modelling tools to generate information for the User Requirements Document (URD) *{ref: 1}*, and this work is performed at the start of the design life cycle. The following phases will see the support system design engineers use simulation-modelling tools to derive the correct number and type of support resources, given the operating activities of the operational system. Concurrently, the financial analysts can apply simulation-modelling tools to derive a forecast of the total through life cost of ownership of the system, taking into consideration the financial risk burden.

Within simulation-modelling applications the formulae and equations use a number of Input Variables, Parameters, Status Variables and Output Variables *{ref 2}*. The tools used within the three main discipline groups use variables and parameters that are not dynamically connected between the groups, but they draw upon common data sets. Three groups have been identified here to illustrate the scope of the attributes that affect Product Effectiveness and Worth (PE&W) *{ref: 3}*, which can be broken down into the following attributes:

- 1) Technical:
  - a) Operational
  - b) Functional
  - c) Physical

- 2) Operational Availability:
  - a) Reliability
  - b) Maintainability
  - c) Supportability
- 3) Through life cost of ownership:
  - a) Concept
  - b) Assessment
  - c) Demonstration
  - d) Manufacture
  - e) In-service
  - f) Disposal

The sub-levels to these groups are dependent upon the specific characteristics of the system design requirements.

## TECHNICAL CONSIDERATIONS

The identified technical considerations are linked in a specific order, which can be seen from the following definitions *{ref 4}*:

- 1) Operational is an activity or series of linked activities to achieve a particular purpose.
- 2) That purpose is provided by the functional characteristic of some thing.
- 3) The thing is a physical reality that can be seen and touched.

Within the defence industry the operational requirements definition is provided by the URD and the System Requirements Document (SRD) provides the functional requirements definition. The physical design is derived based on the specified requirements from both documents. The system operational, functional and physical descriptions are

derived in turn within the CADMID cycle shown in

figure 1 {ref 5} below:

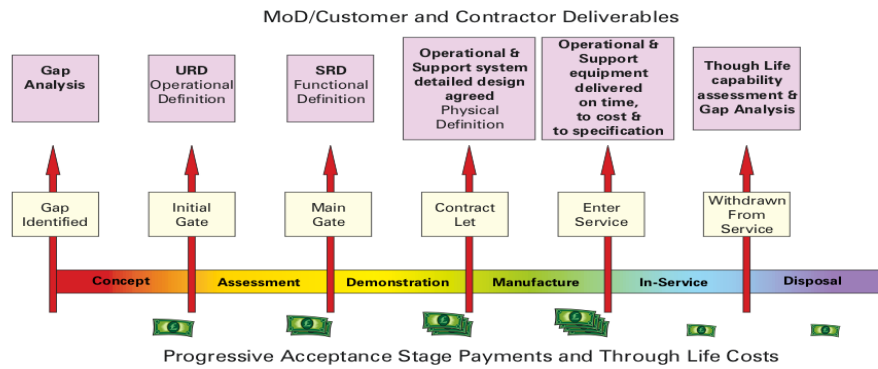


Figure 1: The Defence System Life Cycle

Before any dynamic modelling is conducted, there is value in constructing static models that describe a series of operational activities. Within the commercial world business operations are described using the ICAM (Integrated Computer-Aided Manufacturing) Definition language {ref 6}, commonly referred to as IDEF0. The IDEF0 methodology has been applied internationally for business process re-engineering projects for years, so it represents a tried and tested approach. The process involves deriving and authoring activity models {ref 7}. A worthwhile fact to using IDEF0 is that research has investigated the integration of the IDEF0 static models with discrete event simulation tools {ref 8}.

requires an Operational Analysis (OA) to be conducted, which is normally carried out by the UK Defence Science & Technology Laboratory (Dstl). The OA is derived through the use of dynamic modelling tools, which in turn leads to the written URD. For land systems the tool used is WarFighter {ref 9}, which investigates the operational effectiveness of a number of system capabilities and uses a limited number of vehicle dynamics with the calculations. WarFighter is an evolution of a multisided low level combat war game originally developed by the British Defence Evaluation and Research Agency (DERA) to analyse land warfare. A screen view of WarFighter is provided in figure 2 below.

During the conceptual design phase the United Kingdom (UK) Ministry Of Defence (MOD)

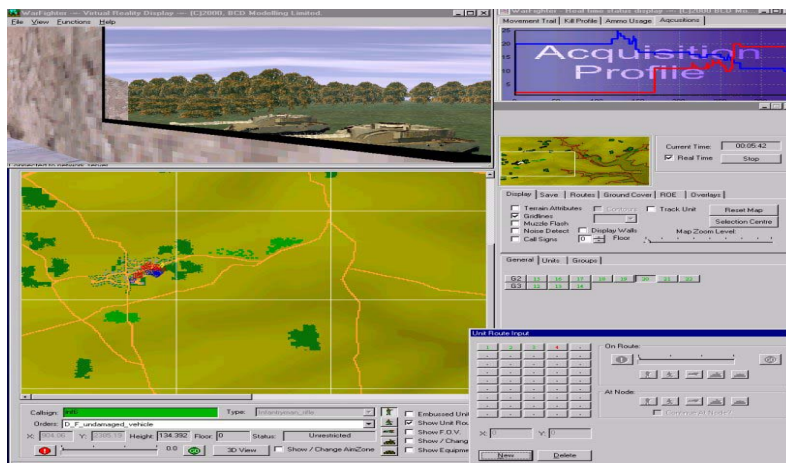


Figure 2: Warfighter from BCD Modelling Limited

The Warfighter application represents action at the individual level, which can be used for the following:

- 1) Operational analysis
- 2) Unit tactical training

- 3) Mission rehearsal
- 4) Commander training

The derived URD provides the basis for those analyses to derive the Systems Requirements Document (SRD) through the Functional Analysis (FA) activities. As part of defining the technical specifications of a system design, functional modelling strategically guides design activities such as problem decomposition, physical modelling, product architecting, concept generation and team organisation *{ref 10}*. The FA model will be more exhaustive and precise if derived using SADT (Structured Analysis & Design Technique) *{ref 11}*, which is the predecessor to IDEF0. The result from the FA invariably has an impact on the URD, which leads to further iteration of the mission profile through the OA tool. The operational to functional relationship at present is not integrated within a single modelling tool, but split between the OA and FA toolsets. When this iteration occurs it is important to maintain the Requirements Management Documentation (RMD), such as the URD and SRD within the linked database structure. The existing toolsets will not allow for direct

communication of data, so the connectivity of the data sets is manually controlled. The updates to the OA, FA and RMD leads to duplication of effort in terms of loading the same interface data that exists into different tools and databases. It would be better to have a dynamic linked relationship between all three, which yields additional benefits through the course of the CADMID cycle.

### OPERATIONAL AVAILABILITY

Constructing an availability block diagram based model is probably the best approach for communicating an overall system availability figure, because it is relatively straightforward to follow the results through the hierarchical structure. The structure can provide the presentation of the results from both an analytical approach *{ref 12}* or a simulation based approach *{ref 13,14}*. One of the most powerful availability simulation tools is called SPAR and its architecture is illustrated in figure 3 below and an overview is provided on the Clockwork web site *{ref 15}*:

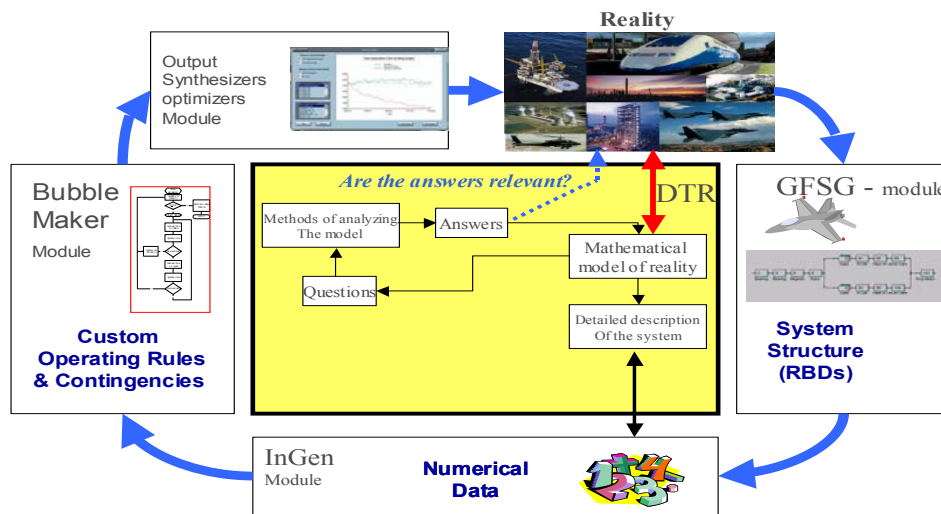


Figure 3: SPAR From Clockwork-Solutions Limited. A Monte Carlo Simulation Tool to evaluate life cycle availability, reliability and maintainability modelling for performance asset management

SPAR uses a reliability block diagram framework with relationship integration being provided by the "Bubble Logic". The relationships include reliability, maintenance, support resource availability, operational scenarios, etc. The results are not graphical without an output module, so the next generation will improve the scope of graphical representation modules by allowing SPAR to be embedded into another application, which could include Visio for the block diagrams.

The block diagram format is a useful facility for communicating the functional description of a system. The visual SPAR product promises to be better due to the improved data connectivity of the information being used and produced and the fact that the calculative engine will be able to be imbedded into another application. The information being generated can be combined and then communicated via the Visio environment. A supporting data sheet can also be produced detailing the following:

- 1) Failure event data
- 2) Maintenance task durations
- 3) Stock out risk of spare parts
- 4) Down time of the system
- 5) Consumption rates of resources

The data sheet will provide a valuable source of information to derive the through life cost of ownership, as well as interrupting the operational activities of the virtual system. The interrupting events include scheduled maintenance, failure and spare parts stock-out.

### THROUGH LIFE COST OF OWNERSHIP

The models used within this environment can range from simple spreadsheets to complex simulations. The basic simulation approach is to draw together all of the events that carry a cost to the customer, taking into consideration the variability of the source data. The through life events are built up from the structure provided by the CADMID cycle (illustrated in figure 1). The level of detail required for each phase is dependent upon the complexity of the system design. The costs through life are usually represented annually, as this will allow for investment appraisal techniques, such as Discounted Cash Flow (DCF) through the Net Present Value (NPV) approach to be calculated. The structure created by cost elements and years of the CADMID cycle lend itself to the production of the through life cost profile and an easy method to identify the cost drivers.

A typical range of cost elements arranged into a basic structure referred to as the Cost Resource Breakdown Structure (CRBS), which can include but are not limited to the following:

- 1) Concept Design Phase
  - a) Project management
  - b) Operational Analysis (OA)

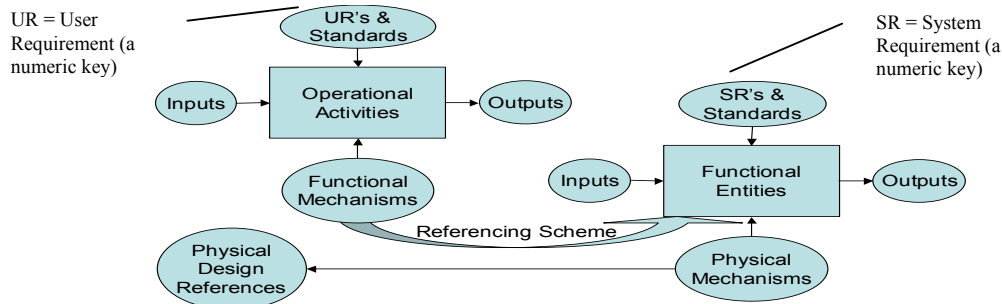


Figure 4: Operational to Functional to Physical Mapping {ref 16}

The structure illustrated in figure 4 is based on the IDEFO approach to both operational and functional

- c) Concept Design
- 2) Assessment Design Phase
  - a) Project management
  - b) Functional Analysis
  - c) Preliminary Design
- 3) Demonstration Design Phase
  - a) Project Management
  - b) Detailed Design
  - c) Equipment Selection
- 4) Manufacture Phase
  - a) Make or buy system parts
  - b) Integrate Parts into Whole
  - c) Test System
  - d) System Acceptance & Roll-Out
  - e) Initial Training
- 5) In-Service Phase
  - a) Continuation Training
  - b) Operator costs
  - c) Maintainer costs
  - d) Spare parts consumption
  - e) Fuel consumption
- 6) Disposal Phase
  - a) Dismantle and Recoup any scrap value or sell-on

### HOLISTIC APPROACH

The holistic approach to system engineering design is to assess the design solutions from the PE&W perspective, in both static and dynamic terms. The assessment will require the technical, operational availability and through life cost considerations to be linked in some way that will allow the dynamic modelling tool to derive the PE&W results. The variable and parameter data mapping method for PE&W investigations has been derived based on the relationships stated in the previous sections. The stated relationships in summary are operational, functional and physical knowledge, which is required for the discipline groups in support of their analytical activities. The derived relationships structure is illustrated in figure 4 below:

system descriptions. The difference here is the descriptions are linked through a data key

relationship that is able to look forward to the functions and back towards the operational activities. IDEF0 was chosen because it is a member of a method family that is one of the more widely used multi-perspective representations of knowledge methods {ref 17}.

The idea of linking two IDEF0 models to provide the operational to functional to physical data mapping came from experience within the defence industry in the application of the progressive acceptance case process. The process involves providing the customer with the engineering evidence that justifies the existence of any equipment item or support resource with respect to the URD and SRD key requirements (i.e., URs & SRs). The data audit trail needed to be easily understood and support the analytical activities employed in the design and development of the combined operational and support system. The critical system information that drives all the design work is the functional description, which cannot exist without the context of the operational mission profiles.

Another important point to the use of two models (Operational and Functional) is the link to the dynamic model in the form of Monte Carlo simulation. For example, there are operating and non-operating events that occur with some degree of variance of event characteristics, such as:

1) Operating event characteristics:

- a) Initiating action for each operational task sequence in terms of mission profile with options
  - b) Operational Task Duration
  - c) Interrupting action frequency, in terms of loss of functional mechanism
  - d) Closure action of each operational task
- 2) Non-operating event characteristics:
- a) Initiating action (linked to 4 above) in terms of the reliability of the physical mechanism
  - b) Maintenance task duration
  - c) Spares administrative delay time
  - d) Spares availability
  - e) Maintainer availability
  - f) Support resource availability
  - g) Logistic delay time for:
    - (i) Spares
    - (ii) Maintainer
    - (iii) Support resources
  - h) Closure action to return physical equipment to a functioning state

Each of the time durations and frequencies of occurrence will vary in value, which can be dealt with through the application of Monte Carlo simulation. For example, the following simulation logic sequence diagram was derived to help construct the operating logic of a SIMUL8 simulation model for land systems:

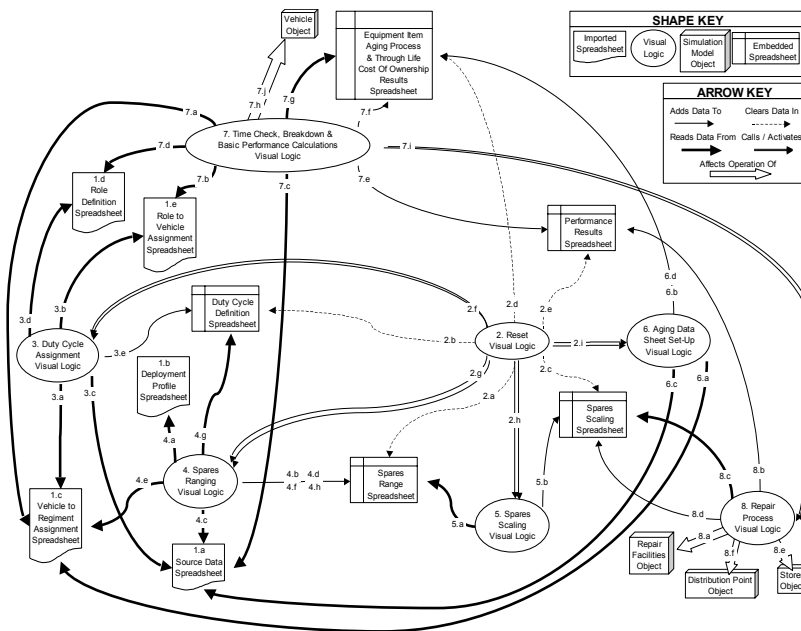


Figure 5: SIMUL8 Application Operating Logic Diagram

Figure 5 above is a useful picture to illustrate the relationships between the operating events, non-operating events, model objects, data tables (spreadsheets), control logic (Visual Logic in SIMUL8) and the process sequence.

- 1) Group 1 are the spreadsheets that are manually loaded into the SIMUL8 environment, but these can be replaced with data tables that exist within any standard database.
- 2) Group 2 includes the reset logic to clear the SIMUL8 imbedded spreadsheets and to release control to four other logic modules in turn. This group is only activated when a new simulation run is required and represents resetting the model with the latest information.
- 3) Group 3 builds the duty cycle definition data table.
- 4) Group 4 builds the spares range data table specific to individual store locations.
- 5) Group 5 builds the spares scaling for each of the store locations to ensure they have enough spare parts to meet the expected demand profile.
- 6) Group 6 builds and adds equipment item aging data

- 7) Group 7 builds and adds data to the performance results data table. It also adds data to the combined equipment item aging process and through life cost of ownership results data table.
- 8) Group 8 updates the spares scaling data table and adds data to the performance results data table.

Based on the previous sections of this paper it was decided to adopt a graphical based approach to the system design definition, such as using IDEF0. The only viable option was the new Microsoft Visio 2003 software package as it is the first of the Visio tools that can be imbedded into another application {ref 18}. The prototype application of the operational to functional to physical mapping is illustrated in figure 6 below. The Visio based application can associate any data from spreadsheets or database tables to any shape through the use of the custom properties data table within the shape sheet. It is possible to perform calculations that take account of the connected relationships of the shapes and any hierarchical structure that may exist.

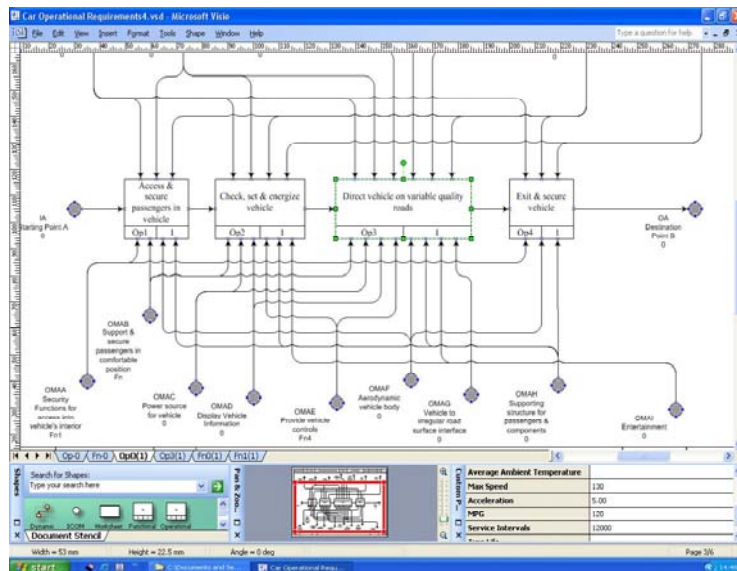


Figure 6: Visio 2003 Operational to Functional to Physical Reference Mapping {ref 16}

The Visio application satisfies the static part of the modelling architecture, which is an important part of the design process. But the missing element is a simulation tool that can deal with the technical design by assessing the mechanics and dynamics of a system within an operating environment. Taking cognisance of the 3D Warfighter example

illustrated in figure 2 above, a commercial example has been found which is more readily available to the public. The example is intended for car design or gaming and the tool is called “Racer”. Racer is a car simulator, which is based on the dynamic vehicle mathematics supplied by Genta {ref 19}.

Racing Game developers {ref 20} also reference Genta's work. The information stored in the Visio application's custom properties data table needs to be communicated to the dynamic modelling part of the Racer car simulator. The link between the Visio environment and in this example the Racer dynamic modelling environment can be achieved through the use of the C++.Net language. This is because Visio allows access for C++.Net and Visual Basic dot Net based applications. The majority of the dynamic

modelling tools that can deal with vehicle dynamic calculations are usually written in a C-based language. For example, the Racer car simulation programme {ref 21} illustrated in figure 7 below has been written in C++. The SPAR operational availability-modelling tool is being updated in the latest Visual Studio environment with its bubble logic being provided for in the latest C++ language. Thus the parts of a holistic modelling environment can be easily integrated.



Figure 7: Racer Car Simulator & Racer Car Engineer Module

The modelling elements to integrate given the above examples are:

- 1) Technical modelling tool, such as Racer
- 2) SPAR type tool for availability modelling.
- 3) Through life cost forecast data sheet.
- 4) Linking tool for PE variables and parameters.

Considering each of these elements can be imbedded in the same dot net-based application, which allows control of the discrete parts, as in the figure 5 example, a holistic system modelling architecture can be established (figure 8 below) {Ref 22}. Validation of each part has occurred individually on specific projects, but the integrated approach will also need to be validated once the Visual SPAR part of the puzzle becomes available.

It will be up to the container application to coordinate the activities of the various parts of the holistic modelling environment and will be responsible for time keeping. The application illustrated in figure 5 achieved this by passing control and data over to the appropriate logic code and spreadsheet when specific events occurred. For example, upon a failure event the processing control is passed over to "8. Repair Process Visual Logic", and then passed back upon completion of the maintenance activity.

## CONCLUSIONS

The use of the latest Dot-Net technologies has enabled the design and part-construction of a prototype holistic design simulation-modelling tool. While all of the pieces have not yet been integrated, due to their unavailability, the technical logic works and has been tested in other applications. This paper represents part 1, which is to highlight a path towards achieving a holistic design analysis tool. Part 2 will combine all the elements within a practical working tool and use the completed architecture in a case study, which will prove the trade-off recommendations from specific discipline viewpoints will be different to a holistic recommendation, which is more likely to yield a truly optimised design solution.

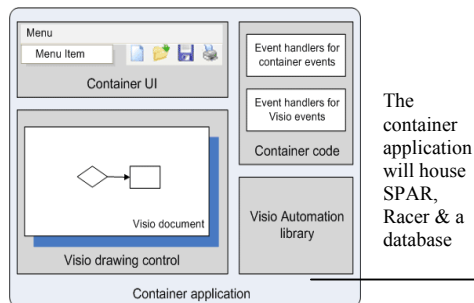


Figure 8: Application Architecture With Visio

## BIOGRAPHY

**Stuart Chandler** has over 12 years 'through-life' systems-modelling experience, which has been gained in many different industrial sectors on a variety of system types. The modelling experience has been gained in the design, development and application of through-life cost, contractor logistic support, private finance initiative, spares ranging and scaling, reliability and availability modelling tools, and has been applied to nuclear power stations, nuclear submarines, air traffic control systems, armoured fighting vehicles, generator sets and gas turbine engines. Stuart gained an MSc in Advanced Manufacturing Systems Engineering from Brunel University in 1996, with a final project in Economic Availability Modelling, and is currently working at Sussex University on a D.Phil. in 'Holistic Design Trade-Off Analysis through Multi-Disciplinary Dynamic Modelling'.



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