Proceedings of the 9th Biennial ASME Conference on Engineering Systems Design and Analysis
ESDA08
July 7-9, 2008, Haifa, Israel

ESDA2008-59297

A NEW TOOL TO IMPROVE ENTERPRISE MODELLING UTILISATION AND DEVELOPMENT

Bilal Wahid **Chenghua Ding** **Richard Weston**

Centre of Excellence in Customised Assembly, Loughborough University, Leicestershire, LE11 3TU UK

ABSTRACT

In recent decades technological innovation has induced very significant change on the way that Manufacturing Enterprises (MEs) operate and compete. In general MEs are very complex entities: designed, managed and changed by people, by deploying people and technological resources in systematic, timely and innovative ways that generate competitive behaviors. Prerequisites to respond such change and deal with complexity are firm understandings of; the processes that are the focus of improvement, and effects of change decisions. However, implementing change and dealing with associated effects can prove difficult when such an understanding is not intrinsic i.e. domains lacking structure and documentation.

This paper introduces a new approach to support enterprise decision making using Computer Integrated Manufacturing Open Systems Architecture (CIMOSA) modeling principles and constructs and enhanced stencils created in MS Visio® and MS Visual Basic®. Current approaches offer little benefit above and beyond paper based solutions and merely serve to provide a visual representation of processes. Such models require that the end user have an understanding of the modeling methodology deployed in creating the diagrams, leaving models prone to misinterpretation. From a model developers perspective, current approaches do not provide support for the capture of modeling decisions or background information, implying that robust understandings can not be had by those not directly involved with the modeling efforts. The added functionality exhibited by the newly developed approach offers great extensions over those currently in use, in terms of; efficient model development, increased data and application integration, and enhanced end user interactivity.

1. INTRODUCTION

Enterprise Modeling (EM) approaches and supporting tools provide a structured view and grounding for change decisions, enabling the systematic hierarchical decomposition of an ME's processes, allowing contextual problem definition and specification. However, the assumption that EM makes is that the model user has an understanding of modeling principles, expecting that the modeler is also the end user. Additional complexities arise when those unfamiliar with the modeling approach used must then understand what lies before of them. This culminates in the models generated being partially understood or open to misinterpretation. Secondly, current approaches to EM have limited software support, with diagrams created enabling a visualization of the process flow. Whilst these are effective in depicting the processes under analysis, they do require numerous supporting documents to capture process related information. Additionally, current tools do not capture the modelers reasoning behind decisions made during model development.

All of the above issues and potential problems necessitate the improvement of EM and supporting tools. For developments to be achieved, deep understandings of; EM principles, model building requirements, and model end user deliverables must be investigated, and appropriate software support tools to realize the above requirements in model generation and deployment identified.

2. ANALYSIS OF STATE OF THE ART ENTERPRISE MODELLING APPROACHES AND SUPPORTING TOOLS

2.1. GENERAL SURVEY OF STATE OF THE ART

CIMOSA (Computer Integrated Manufacturing Open Systems Architecture) was developed by the AMICE consortium during a series of ESPRIT projects [1]. CIMOSA aims to help companies manage change and integrate their facilities and operations. It has been emphasized by Kotsiopoulos [2] and Kosanke [3], and is considered by many authors to be the most comprehensive of current public domain EM approaches [4-6]. CIMOSA introduced a process-based approach to integrated

EM, ignoring organizational boundaries, as opposed to various function or activity-based approaches, described in terms of their; function, information, resource and organizational aspects, and designed according to a structured engineering approach that can then be plugged into a consistent, modular and evolutionary architecture for operational use [4]. It presents a model-based approach to design, operationalize and manage an enterprise.

The Purdue Enterprise Reference Architecture (PERA) is characterized by its layering structure. These layers together present a methodology for the design and operation of a business enterprise as a whole or in part. A comprehensive example of the use of PERA and its methodology is described in [7]. The PERA methodology covers various lifecycle phases of an enterprise starting with identification of the business unit itself and its strategic role and objectives and ending with enterprise operation [8]. PERA does not provide its own modelling language however; other modelling tools and techniques can be used to support its concepts. PERA identifies three classes of entities in an enterprise namely: information, human, and organization. Particular importance has been given to humans and their organization.

ARIS stands for ARchitecture for integrated Information Systems. It deals with business-oriented issues of enterprises (such as order processing, production planning and control, inventory control, etc.). The focus is essentially on software engineering and organizational aspects of integrated enterprise system design [4]. ARIS offers four views of an enterprise at three modelling levels. The three modelling levels are similar to CIMOSA i.e. generic, partial and particular. The four views include: function, data, organization, and control view. ARIS is composed of four levels of process optimization, process management, workflow and application. The ARIS framework which is also called ‘house of business engineering’ covers lifecycle phases from business process design to information technology deployment. The architecture also bridges the gap between business process modelling and workflow driven applications, from Business Process Reengineering (BPR) to continuous process improvement [9].

The authors and their colleagues have been using CIMOSA in numerous research and industrial projects. Sets of CIMOSA conformant models are generated during projects and presented to industrial partners for verification, using CIMOSA conformant approaches developed at the MSI Research Institute, Loughborough University. This serves three purposes; (1) to enable enterprises to understand, model, analyze their processes and operations, (2) to provide model developers with an accurate benchmark from which improvements can be derived, (3) to provide the management team with information to make effective decisions in response to change. For the constraints of this paper, the authors will not go in to great details and illustrations of CIMOSA models, but briefly introduce main modeling procedures followed and the model types produced, to provide a basis for further tool development (see Fig.A1, Annex A for supporting information to the forthcoming explanation).

2.2. CIMOSA MODEL REALISATION AND DECISION SUPPORT

2.2.1 ESTABLISHING A FOCUS MODELING DOMAIN, THE CONTEXT DIAGRAM

After the broad aims and general problems for a case company have been identified, the modeler must define a scope within which the existing modeling tools will be deployed. EM in this case uses decomposition principles to handle model complexity, this constrains the modeler to model in abstraction and avoids modeling of the infinite complexity inherent to real systems. The modeling priority and emphasis is established through a model depicting the global objective, which is reasonably simple in structure and content. The primary focus is central and surrounded by the most relevant domains involved in objective realization. This is termed the Context Diagram, and is the first type generated. Additionally, it is necessary to have specified an area of concern when drilling down and to demarcate immediately unconcerned domain(s) to provide succinct models, representative of entry point and problem concerns. Marked domains are then treated as ‘black box’ thus not further detailed during model development nor when creating modeling scenarios for case companies.

2.2.2 PROBLEM DOMAIN DECOMPOSITION, INTERACTION EVALUATION AND STRUCTURE BUILDING.

The next modeling step deploys a mechanism for decomposition to break down the primary focus domain, CIMOSA modeling specifies a diagram to show relationship networks between those involved domains. The relations are interpreted in terms of inflow and outflow of; information, human resources, material and finance. Thus when a particular domain is subjected to internal change, one can deduce the inter-domain effects on connected flows and responses. This is outlines the purpose for the Interaction Diagram. A subsequent type of diagram, termed the Structure Diagram, is used to decompose and build structure. This can also be used on each of the associated domains which have been identified to model in CIMOSA in the Context Diagram. The Structure Diagram takes each domain as a focus for further examination and decomposition in to a hierarchically structured set of processes. Both types of diagrams can be built on a subsequent level i.e. it is possible for a particularly complex domain to have several Interaction and Structure Diagrams for the purposes of providing a sufficient level of detail as required by the modeler.

2.2.3 SEQUENTIAL PRECEDENCE OF PROCESS OPERATIONS, THE ULTIMATE RESPONDENTS TO CHANGE AND WHERE DECISIONS NEED TO BE MADE.

Procedural steps thus far have served to decompose and structure domain contents. Now a more detailed level is reached, here actual sequences of process and constituent operations are assessed. Complete end-to-end process networks, comprising activities with associated information and resource inputs and outputs are represented using the fourth CIMOSA diagram type, the Activity Diagram. A numbering convention is followed to identify activities listed with their dependencies and routings. Also, an approximate duration is given through means of a timeline indicating when each step of operation will initialize and how long they operate.

From a model developer and theoretical perspective, the concepts, methodology and technology used in CIMOSA modeling and diagrams, can usefully decompose complex process networks into their component process segments. CIMOSA also serves to provide a means of documenting and visualizing associated flows of; activities, material, information, controls and so forth. Such model diagrams can support an ME's decision makers (i.e. company management teams and direct associated operators) who require increased information support from models. To achieve this, the models need to enable; (1) appropriate presentation format and structure to be readily understood by users (i.e. the decision makers) (2) efficient and equivalent information which can be quickly obtained from models, (3) quick, responsive and efficient development, if original model data is available, as per the end users' reference requirement, (4) a model format and building procedure that is flexible to various model iterations, transfer, and re-use.

2.3. EXISTING TOOLS AND THEIR LIMITATIONS

Several software tools exist to support EM using previously outlined approaches in section 2.1. However, such tools inherently have the same limitations as the modelling approaches they are founded on, with the added disbenefit of them being proprietary in nature i.e. not open source. Examples include:

- EDraw Flowchart® Software [10] supports IDEF with provision of basic flowchart diagrams, with very limited functionality and no re-use or subsequent programming capability
- Corel IGrafx® IDEF0 [11] for creating flowcharts and diagrams to analyze business models, this has enhanced functions however, this comes at a relatively high cost. This is a commercial software as opposed to open source
- ProcessWorks!® [12] supports BPR and activity modeling to establish understandings, reshaping and improvements to current Business Process(es). ProcessWorks! gives an overall picture or "roadmap" of an ME and it's activity modeling tool allows visualization of current processes, thus enabling an understanding of business requirements
- ARIS® platform series [13] is an platform of products that enable MEs to continuously improve their Business Processes. They cover the entire scope of a BPR project, from strategy definition and process design through transformation of models into IT applications and monitoring of process execution.

It is noted that none of these software tools exhibit support for CIMOSA. Additionally, none of these allow for integration with other tools to aid decision making, i.e. discrete event simulation software, in an open manner. Lack of software tools has meant that the current approach to EM enabled decision support, using CIMOSA, is as conceptualized in Fig.1. This shows that both the model developer and user must have an understanding of CIMOSA and that many model and decision supporting documents must be used concurrently during decision making.

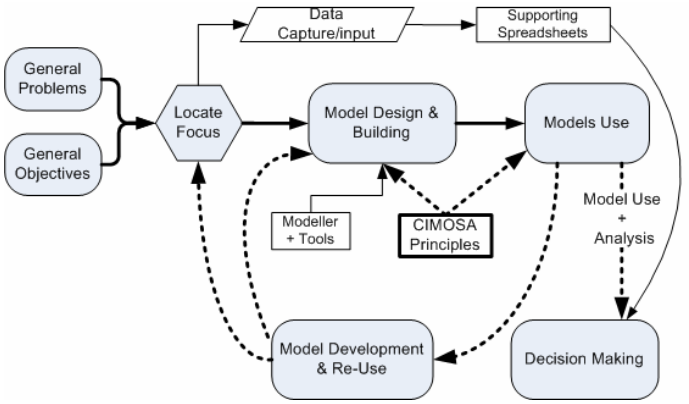

Fig.1 Current model development and use

Previous project work entailing large amounts of modeling effort have given much valuable insights in to the achievement of the requirements detailed in section 2.2.3, the authors have reviewed and analyzed the modeling methodology and technology to find that models are:

- Manually built, time consuming, and lead to non-standard model formats. There is no mechanism to provide supporting information documenting the modelers thought process during model realization
- Difficult to interrogate and search for specific information across a set of models i.e. are weak in delivering information to users and offer little advantage over paper based models
- limited in support for translation in to discrete event simulation software both in terms of model structure and supporting information
- seldom re-used i.e. do not support model building blocks and built-in information
- non-supportive of collaborative working environments i.e. parallel modeling creating (different modelers working on

different model domains and sharing information with limited duplication).

As non-standard models were developed, there was very little concurrent effort in the development of a supporting CIMOSA Enterprise Modeling (EM) tool. The majority of the model building is completed manually, with functionally limited (when considering the application area) computer software tools used such as MS PowerPoint®© and SmartDraw®©. Consequently; models take a large amount of time to create, provide poor visual presentation as the diagrams vary in format from different modelers, and rely on the modelers' knowledge and skill of the software tool used. Additional challenges are faced when considering more complex domains and processes. The sequence of models created will depend on the model builder, there could be dozens of models of all types. Their relations are guided by CIMOSA numbering conventions, however, the logical hierarchy and sequence between diagrams are still hard to follow by ordinary users who have little professional modeling knowledge or background.

From a model user aspect, most are familiar with their processes in the real world, however very few have equally developed understandings of modeling principles. While modeling complex process networks in an ME, large numbers of diagrams are needed to break down complexity and provide detailed information. This has been a common occurrence drawn upon from the authors' experience, users are not able to readily switch from a functional, departmentalized view to one that is objective, context, and process oriented. This impacts comprehension of models and decomposition principles intrinsic to the diagram hierarchy discussed previously. Currently there is no known effort to make models that are more 'user centric'.

More importantly, the purpose of EM and CIMOSA is to provide understandable information to model users, who are in most cases, not directly involved in model development. Thus the models' current presentation format induces difficulties for such users to easily follow and understand what lies before them, and successfully create the link between the modeled and real systems.

The above requests from both modelers (decision making supporters) and users (decision makers), and the weakness of current CIMOSA modeling tools to satisfy the requirements, has raised the essential need for improvement.

This paper addresses this established need beginning with EM using CIMOSA principles, with focus on supporting the inexperienced model user who is tasked with making organizational decisions and would thus benefit from guidance in identifying and resolving problem domains. Using an existing commercial software tool as a development platform, enhancements to model visualization and interactivity have been realized, later sections also demonstrate the improved automation and configurability during model building, as the tool is targeting improvements in functionality from the perspectives of both the model user and developer.

The paper then illustrates the developed tools via an exemplar case study, with the purposes of establishing practical usage and analysis with third party (industrial user side) verification, with feedback informing further development potential.

3. PROPOSED NEW TOOL TO IMPROVE ENTERPRISE MODELLING

The main aims of developing the new EM tool are to enable; users to easily visualize a complex process and it's supporting resource and information systems (to support decision making), and model developers to efficiently produce and document models.

The new tool development is heavily dependant on the authors and their in depth understanding of CIMOSA modeling principles, as well as an advanced understanding of Visual Basic® and Microsoft Visio®. The foregoing discussion centered on the lack of appropriateness and support currently exhibited by software tools used. The proposed new approach to model building, depicted in Fig.2, allows for the integration of user and model developer areas that were previously inferred.

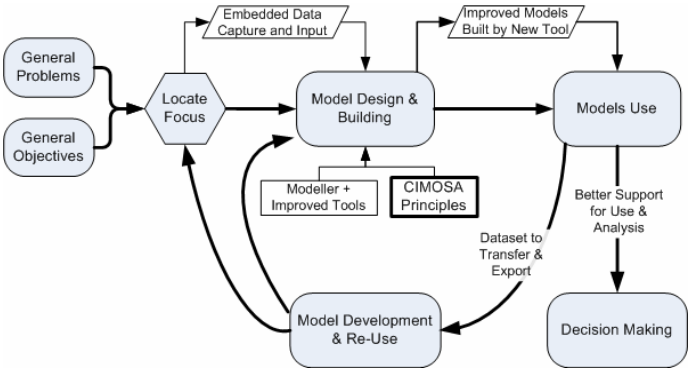

Fig.2 proposed new approach

The basic functionality of the MS Visio® software is very similar to previous alternatives used to produce graphical representations of the domain under study. However the substantial improvements developed through the proposed tool are:

1. Embedded CIMOSA principles during model development so the user does not have to be well versed in this area, simply click to reveal detail
2. Efficient model building through drag and drop interface with pre-defined constructs and associated 'attributes'
3. Capture of the modelers decisions and process related measures. These can later be exported to inform discrete event simulation packages.

From a developer perspective, there is an element of training specifically aimed at producing models that are not only representative of the real system under analysis but also incorporate the added user functionality (that the new tool enables). Hence a new model building methodology must be

adopted for the proposed tool to deliver efficient and user centric models. CIMOSA EM principles remain central to the new approach i.e. models are designed based on the CIMOSA framework. The set of diagrams generated are as before i.e. context, interaction, structure, and activity diagrams, however these are constructed from a stencil with formal attributes assigned to each of the CIMOSA modeling constructs. The new approach requires the following modeling steps (refer to supporting diagrams in Annex B):

1. Populate diagram information
2. Populate with constructs and attributes as per modeling level and associated CIMOSA principles
3. Create 'parent-child' links as per process decomposition
4. Export to HTML format for wider/user presentation

The initial page layout incorporates important model control information. This aspect of document control, when used in conjunction with the built in 'track changes' function in MS Visio® allows for effective and controlled collaborative model development and review. Attributes within the 'page border' construct are drawn from the modelers PC and automatically entered.

As the modeler develops models, constructs are dragged from the stencil (Fig.3) and dropped on the page (Fig.B1).

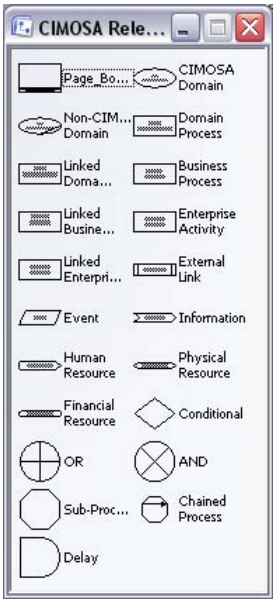

Fig.3 CIMOSA stencil supporting new approach

On performing this action a dialogue box is triggered, this serves to ensure that all relevant information is entered (Fig.B1). This alleviates the need for supplementary spreadsheets containing such information as it can be stored at source i.e. within the modeling environment and attached to the concerned activity or process. This information also serves to inform the model user during review, and to populate further dynamic modeling efforts.

Upon creating a set of models, the next step is to create parent-child links according to CIMOSA decomposition principles, as illustrated in Fig.4. the purpose here is to give the model user the ability to break down complex domains contextually but without necessarily having to understand underlying principles.

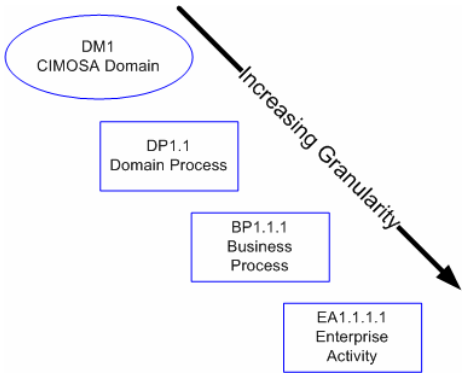

Fig.4 CIMOSA constructs decomposition

Currently the new tool requires that the links be created manually. However, due to some diagrams containing duplicate information, the new tool does exhibit automatic linking and synchronization of textual content for constructs that are duplicated. Constraints on shape size and editing visual appearance enforce a uniform representation of constructs.

Once the set of models is completed, they can then be converted in to HTML format to allow for easy sharing and use i.e. no proprietary software is required. Hence this serves as an off the shelf solution for model users, as the model building knowledge lies with model developer and the stencil with embedded functionality as developed by the authors.

The HTML document produced then serves as the primary interface for the model user. The user's ability to manipulate and interrogate models is non-existent in the current approach. The interactive nature of the new approach means that users are more likely to feel encouraged to explore models and their contents, currently this require sifting through diagrams in conjunction with a briefing document outlining the methods deployed by CIMOSA. Referencing Fig.B2 (Annex B), the model user is now able to:

- Zoom and pan, in overview, complex model diagrams to locate a focus
- Explore model structure through automated links between diagrams and process segments, providing much needed model routing guidance
- Navigate directly to diagrams by means of a drop down box
- Review specified entity attributes, populated by the modeler and reflective of the actual system, viewable by clicking
- Search to mine all model content (including construct text and attributes) to return all occurrences of search string.

For the purposes of subsequent simulation modeling efforts, it is possible to export attributes related to each construct (e.g. process times, costs, frequencies) in a format that is then readily importable to simulation modeling software.

4. CASE APPLICATION OF APPROACH

The current tool has been discussed at length and the models in Annex A are exemplar of a previous application. The new approach has been subjected to use with a number of recent projects undertaken by the UK Centre of Excellence in Customised Assembly (CECA) as part of project work with large, global, aeronautical and automotive manufacturers. For the purposes of this paper, models will not be presented but outcomes of the new methodology discussed.

4.1. Case application: Company X, Aerospace Supplier

The design and development of new products entails rigorous test and qualification procedures. The methods deployed for Design for Manufacture (DFM) and Design for Assembly (DFA) must be equally as robust yet efficient and timely, to avoid building in costly design decisions affecting a product's manufacturability. The DFA/DFM processes deployed at the case company were not understood and displayed potential room for improvement to more utilize virtual modeling tools and techniques. As a consequence the case company required their current approaches formalizing with a view to exploring the feasibility of a new approach to DFA/DFM.

Initial model development was followed as described previously to ascertain the current state of the system (AS-IS). With the new approach in place, it was straightforward to perform a number of iterations with speedy verification of models built.

With a common and verified set of models agreed, it was then straightforward to use this understood benchmark as a basis for improvements. These were suggested through a series of future state (TO-BE) models created with reference to the CECA DFA/DFM toolbox. Company X were then able to visualize the impacts of implementing the new approach, also how and where virtual engineering tools would be required to provide DFA/DFM decision support.

In terms of CIMOSA model generation using the new approach, a number of issues arose with the stencil which can be broadly categorized thus:

- Graphical or aesthetic
- Attribute definition, import and extension
- Data collection support
- Numbering and linking.

Overall, the new approach offered significant improvements in terms of development time and ability to convey more content rich models. Graphical and aesthetic issues were encountered with constructs not re-sizing correctly, additionally the positioning of shapes still required fine tuning thus improvements in this area would provide models that look tidier.

The attribute definitions at this stage require more theoretical work and are not as well formed as they need to be. As a consequence these were not exploited as fully as they potentially could be.

Data collection required to support attributes and also model generation is not currently, or in the new approach, elicited thorough an integrated and structured means. The ability to elicit process related information through structured questions sets which can then be integrated in to modeling efforts would prove an advantageous extension.

Numbering and linking of shapes, whilst effective, proved to offer slight advantages over the current approach, however the potential to automate this aspect would provide huge savings in time during model generation.

The HTML user interface was easily comprehended and served as a good tool to enable users to visualize processes and their constituent elements. The additional navigation functionality and being able to search provided users with features one would associate with electronic documents.

5. CONCLUSIONS AND FURTHER DEVELOPMENT WORK

Current approaches to Enterprise Modeling (EM), and supporting tools, require refinement to enable model users to fully benefit from model developer efforts. The new approach proposed by the authors of this paper enables substantial improvements over tools currently in use.

The annotated figures contained within Annex B elaborate on the new tool's functionality further, detailing the use of attributes and other developer aids. Diagrams can be exported to a platform neutral format (HTML), and with the aid of an XML plug-in, diagrams can be searched and zoomed giving increased functionality from a model user's perspective. There are also additional improvements that promote uniformity and standards across models built, for instance; model naming and numbering conventions, model revision control.

The work was instigated as a consequence of combined experiences of the authors on project work using the current approach. Failings of this approach generally and notably include:

- Lack of model developer support
- Lack of user support
- No Model integration
- Limited Model re-use.

The new approach provides responses to all of the above and there is also room for additional improvements to better the new approaches ability to address the above bullets, by:

- Improved integrations with simulation models
- Improved integrations with simulation models
- Configure batch data import/export across different modeling approach boundary

- Attribute definition, standardization across models, which would be introduced by a sister paper
- Extension in to data collection and templates
- Automatic numbering according to CIMOSA numbering conventions.

Ongoing work at CECA and by the authors in particular aims to extend the approach to cover the aforementioned thus culminating in an integrated decision support, information delivery, data management and exchange approach for discrete event simulation and similar modeling tools.

6. ACKNOWLEDGMENTS

The authors would both like to acknowledge the guidance and assistance received from colleagues at the Manufacturing Systems Integration (MSI) Research Institute and the Centre of Excellence in Customised Assembly (CECA), Loughborough University, Leicestershire, UK, in the preparation of this paper and supporting tool development activities.

7. REFERENCES

[1] ESPRIT Consortium AMICE (Eds.), 1993, "CIMOSA—Open System Architecture for CIM", 2nd revised and extended edition, Research Report, ESPRIT Project 688/5288, Springer.

[2] Kotsiopoulos, I. L., 1999, "Railway operating procedures: regulating a safety-critical enterprise", Computers in Industry, Vol.40, Iss.2-3, pp.221-230.

[3] Kosanke, K. and Zelm, M., 1999, "CIMOSA modelling processes", Computers in Industry, Vol.40, Iss.2-3, pp.141-153.

[4] Vernadat, F. B., 1996, "Enterprise Modeling and Integration: Principles and Applications", Chapman & Hall, London.

[5] Monfared, R. P. and Weston, R. H., 2000, "A method to develop semi-generic information models of change-capable cell control systems", Computers in Industry, Vol.41, Iss.3, pp.279-294.

[6] Reithofer, W. and Naeger, G., 1997, "Bottom-up planning approaches in enterprise modeling – the need and the state of the art", Computers in Industry, Vol.3|3, Iss.2-3, pp.223-235.

[7] Rathwell, G. A., and Williams, T. J., 1996, "Use of the Purdue Enterprise Reference Architecture and Methodology in Industry" (the Fluor Daniel Example). In Proceddings of the IFIP TC5 Working Conference on Models and Methodologies for the Enterprise Integration, Peter Bernus Laszlo Nemes, Eds., Chapman & Hall, London, 12-44.

[8] Kosanke, K., 1996, "Comparison of enterprise modelling methodologies", in Goossenaerts, J., Kimura, F., Wortmann, H. (Eds),Proceedings of the IFIP TC5/WG5.3/WG5.7 International Conference on the Design of Information Infrastructure Systems for Manufacturing (DIISM'96), Chapman & Hall, pp.115-27

[9] Scheer, A.-W., 1998, ARIS: Business Process Frameworks, Springer-Verlag, Heidelberg

Websites:

[10] EDraw Flowchart Software: website http://www.edrawsoft.com/index.php

[11] Corel IGrafx IDEF0: website http://www.igrafx.com/

[12] ProcessWorks!:website http://www.wizdom.com/processworks.html

[13] ARIS: website http://www.ids-scheer.com/en/Software/89359.html

ANNEX A

PREVIOUS APPROACH TO CIMOSA MODEL DEVELOPMENT AND USE

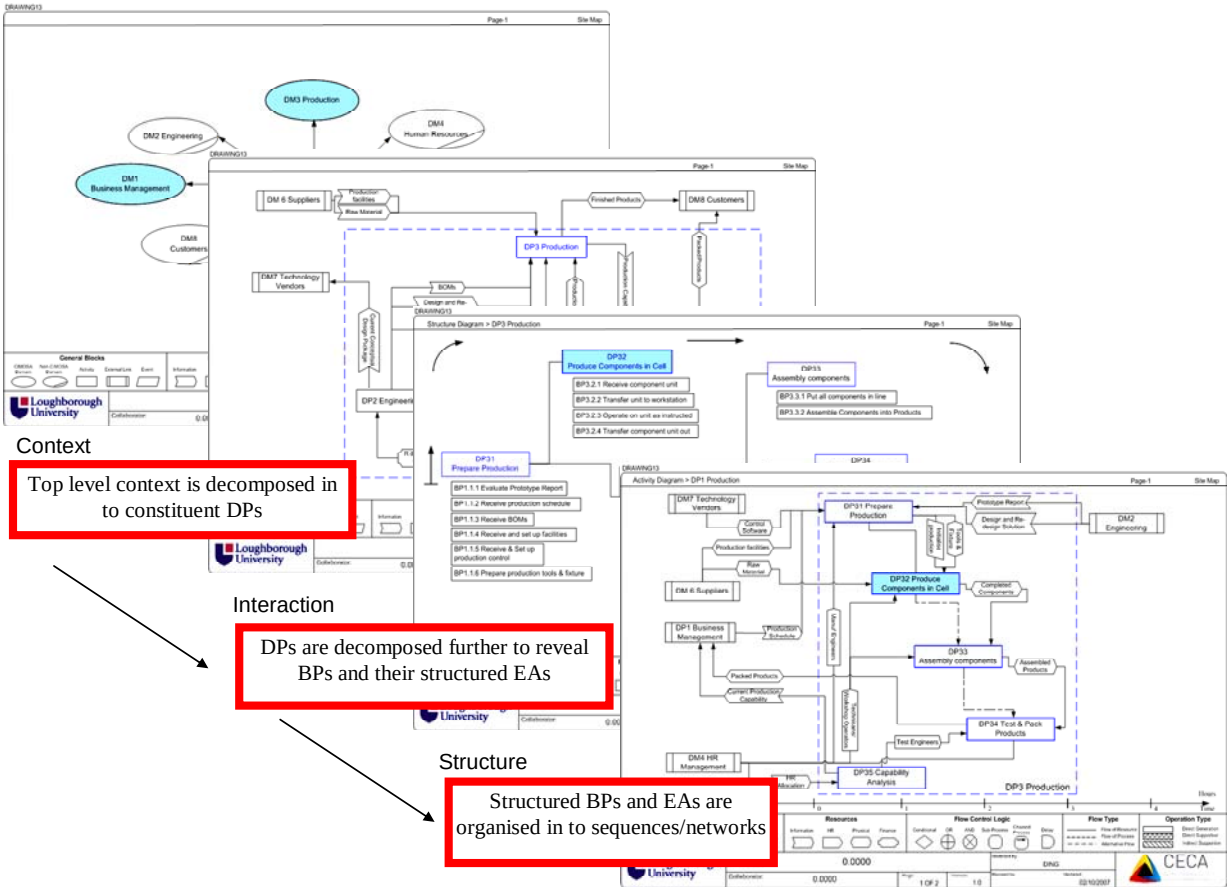

Fig.A1 Example MS PowerPoint ® models that serve purely as a means of visualizing a problem domain.

ANNEX B

PROPOSED NEW APPROACH TO CIMOSA MODEL DEVELOPMENT AND USE

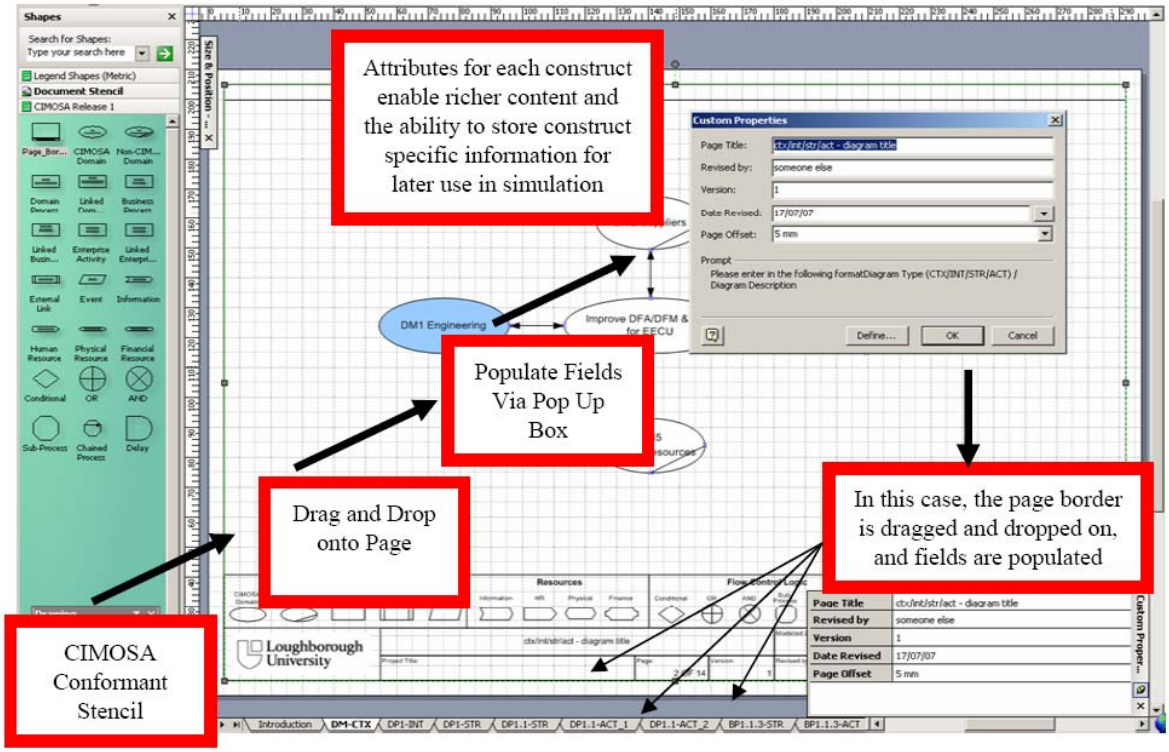

Fig.B1 New approach, drag and drop functionality

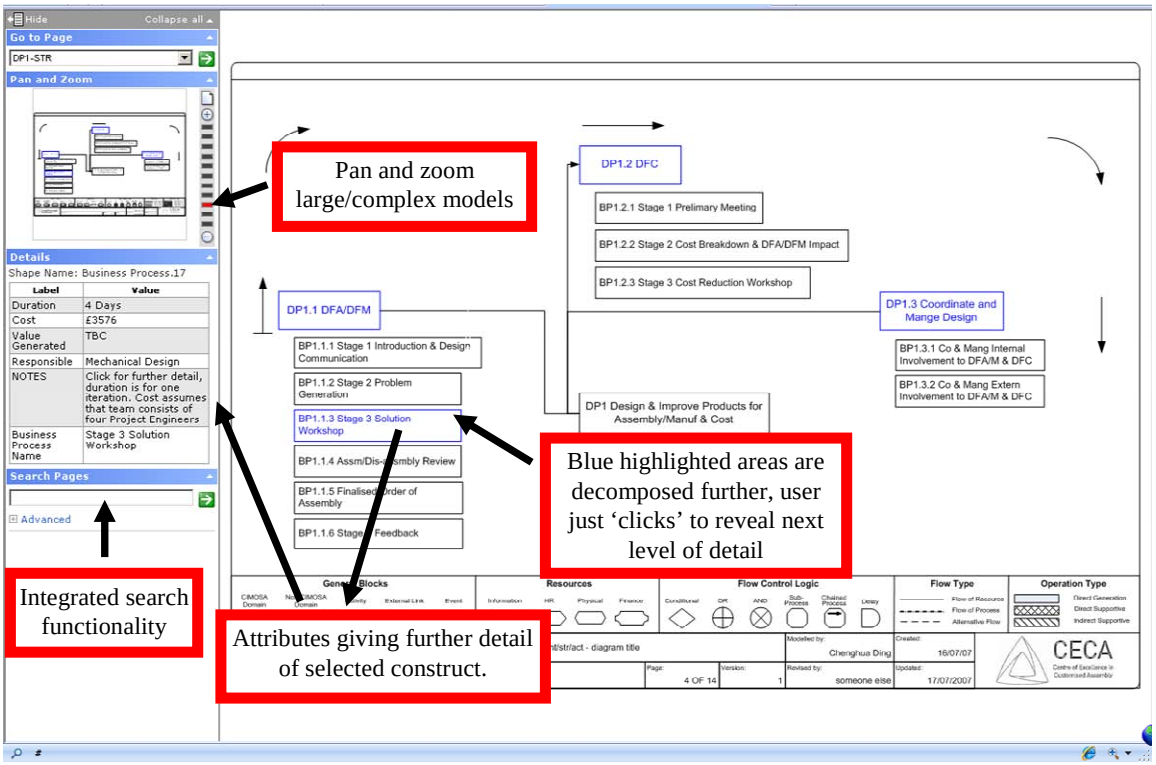

Fig.B2 HTML Model user interface and functionality