SYNTHESIS REPORT

FOR PUBLICATION

Contract No: **BRE2-0533**

Project No: **BE 7094**

TitIe: **AMBITE (Advanced Manufacturing Business Implementation Tool for Europe)**

Project Co-Ordinator: **CXMRU, University CoHege Gahvay, Ireland.**

Partners: CHMRIJ, University College **Galway, Ireland.**
CIM Institute, Cranfield University, England.
FZI, University of Karkuhe, Germany.

Starting **Date: 01/01/94** Duration: 30 **Months**

Project Funded by the
European Commission under
the BRITE/EURAM Programme

Date: 21/08/96

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Analysing the Impact of Strategic Decision Making on Manufacturing Performance.

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Abstract

The take up and use of a new manufacturing technology by an industrial company is directly related to ability to quanti~ the likely impact of such technology on its business. In this paper, the work undertaken in the AMBITE project is described. In this project a decision support framework was developed along with a set of analysis tools that enabled senior managers to determine the effects on their businesses of investing in new technologies or programmed.

1.0 Introduction

The take-up and use of advanced manufacturing techno~ogy by an indusmid company is directly related to its ability to quamti& the likely impact of such technology on its business. Major investments must be seen to be compatible with company business goals. The implementation of technologies and/or programmed - such as Flip Chip, Chip On Board (CO13} and Multi Chip Modules (MCM) in the electronics industry and Concurrent Engineering (CE}/Lean Manufacturing (LM) in the engineering sector - has tremendous consequences in terms of people, skills and manufacturing systems design [1].

This paper describes the work undertaken in the AMBITE [1] project. The objective of this project was to develop a decision framework and a set of amalysis tools that would enable senior managers to determine the effects for their businesses of investing in new technologies. This paper starts by describing the overall scope of the AMBITE project. Each of the separate stages involved in using the AMBITE framework are then described,

2.0 The AMBITE Project

The Advanced ~anufacturing Business ~mplementation Tool for I@rope (AMBITE) project was a fimdamental research ~roj ect funded by the European Union through the Brite-Euram research programme. The project consortium was composed of three academic partners (UCG (IRL), Cranfield University (UK) and University of Karlsruhe (D)) and seven industrial endorsers (Alcatel, British Aerospace, British Steel, Daimler Benz, Digital Equipment Corporation, Ford Motor Company and Kewill). This project had a number of objectives, which included [2]:

- Accelerating the take-up of new manufacturing technologies and programmed.
- Providing tools to evaluate the impact of such technologies and programmed.

- Developing a statement of manufacturing strategy which is consistent with the business strategy of an enterprise.

In order to achieve these objectives, several tasks were completed. The first task involved the development of a fhrnework that allowed the strategy of the enterprise to be expressed in terms of measures of manufacturing performance (MOMPS). These MOMPS could then be customised to reflect the operations of various manufacturing enterprises. The second task involved the development of detailed semantic models of specific manufacturing technologies or programmed. In this project, detailed models for Interconnect Technology and Concurrent Engineering were developed. The third task involved the development of a set of analysis tools that allowed the impacts of introducing a specific manufacturing technology/programme on the manufacturing performance of the enterprise to be assessed.

Each of these tasks corresponded to a specific stage in the AMBITE Framework, and this framework is now described in some detail.

3.0 The AM131TE ~lYHIlE!WO&

The introduction of a new manufacturing technology or programme, such as Chip on Board (COB) or Multi-Chip Modules (MCM) in the electronics industry and Concurrent Engineering or Lean Manufacturing in the engineering sector, has many far reaching ramifications for the company involved in terms of people, skills and manufacturing systems design. The question of whether or not a new technology/programme should be taken up is fm more likely to be answered positively if the likely impacts of such a decision should be quantified. The investment in the new technology/programme must not only make sense in terms of the manufacturing functions, but must also be in harmony with the company's strategic goals.

The difficulty arises because manufacturing enterprises have become such complex organisations that the effect of a particular technology}progrzunme is rarely either obvious or straightforward. The traditional technique of senior managers using their intuition is of littIe use when faced with programmed such as Lean Manufacturing which radically alter every aspect of the manufacturing function. It was clear that a framework and a corresponding set of tools which allowed the effects of a new programmehechnology to be analysed would prove very useful.

The construction of such a framework and toolset was the goal of the AMBITE project. The AMBITE framework was composed of three stages [see Figure 1} which were linked by a common set of measures' of manufacturing performance (MOMPS). Stage I was specifically concerned with the translation of the business strategy, expressed in terms of critica~ success factors (CSFS), into a "specific MOMP map", Stage H was concerned with the translation of knowledge about the technology/programme into a "specific technology/programme model". The detailed information required in this stage to build the specific programme/technology models was provided by the project's industrial endorsers. Once both of these stages were completed a set of analysis tools were used to relate the "specific MOMP map" to the "specific tedrmolobgy/programme model".

This analysis occurred in Stage 111 of the AMBITE framework and resulted in a set of implementation issues.

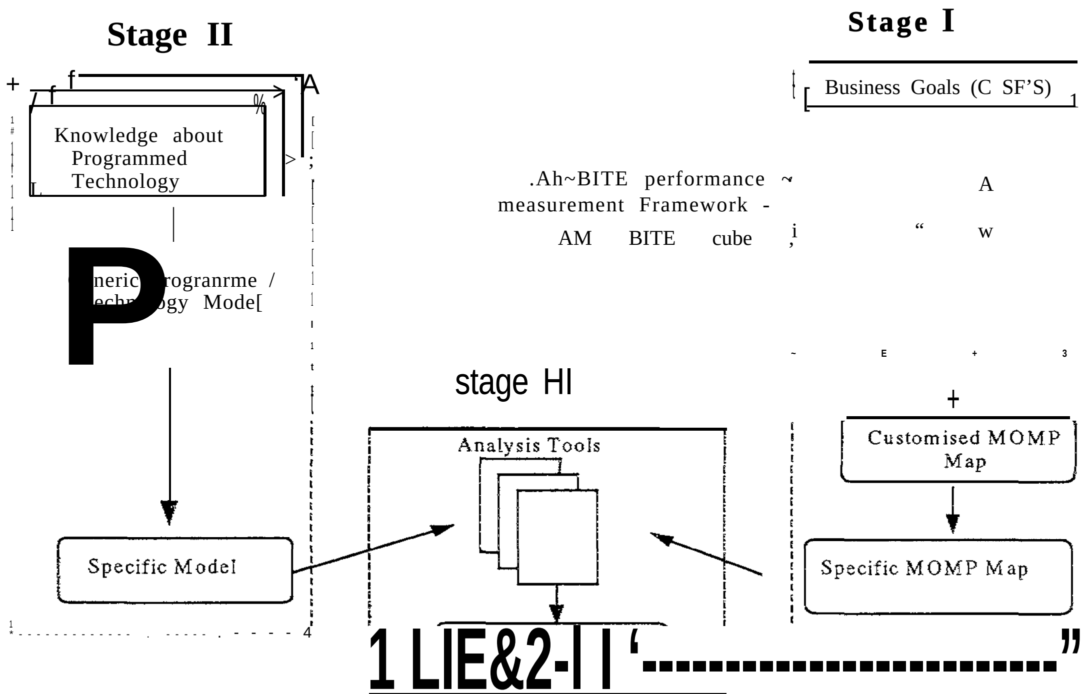

Figure 1: The AMBH'E Framework [2],

Each of the three stages composing the AMBITE framework are now explained in more detail.

3.1 AMBITE - Stage I

The objective of Stage I of the AMBITE framework was to develop a framework that allowed the strategy of a manufacturing enterprise to be expressed in terms of performance measures. This was done by describing the strategy in terms of critical success factors {CSI?S) and then using the framework to identifj a "specific MOMP map" that was related to these CSFS. Effectively Stage I involved the selection of appropriate strategic performance indicators {SPIS) (based on the CSFS), the generation of a generic MOMP map and its subsequent customisation (if necessary) into a "specific MOMP map". In Figure 1, Stage I is described pictorially as **a** set of steps. These steps are as follows:

* Develop AMBITE Performance Measurement Framework
* Develop generic MOMP map
* Customise MOMP map, and
* Develop specific MOMP map.

Develop AMBITE Performance Measurement Framework

The AMHTE performance measurement framework was represented pictorially as a cube (see Figure 2), onto which the business goals of the organisatiorl were mapped in terms of three dimensions; manufacturing typology, manufacturing enterprise processes and macro measures of performance. Each point within this cube, as defined by its co-ordinates, was identified as an SPI (strategic performance indicator). Thus, there were potentially 10CI SPIS within the fbnework. The strategy of the manufacturing enterprise was expressed in terms of critical success factors (CSFS) and these t%Fs were used to-identifi related SPIS.

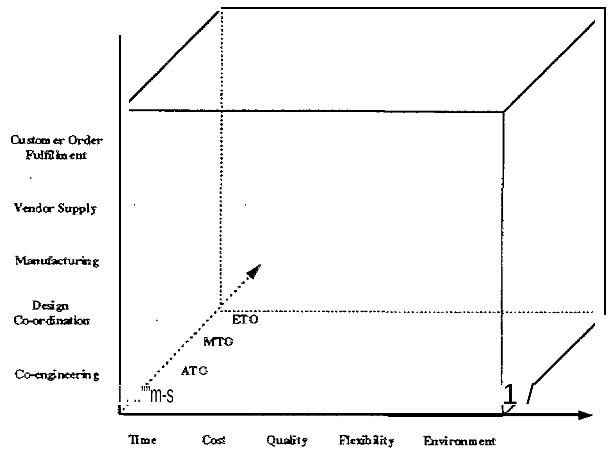

Figure 2: **The AMBITE performance measurement framework [3].**

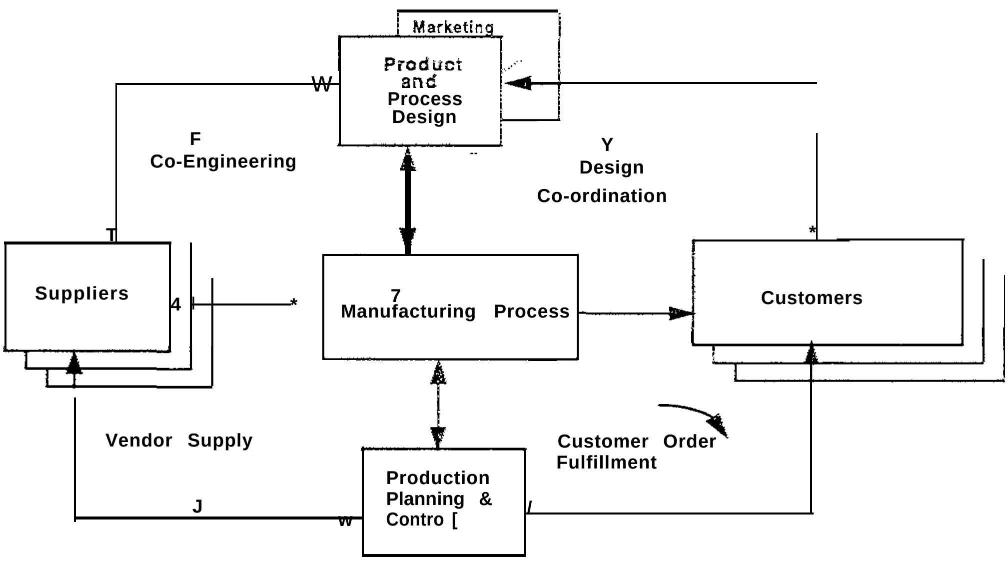

Figure 3: **AMBITE Business Model [3].**

The processes within the manufacturing enterprise processes were derived from Figure 3. This was the CIMN_J model of the manufacturing enterprise within which five distinct business processes were identified [3]. The five business processes were as follows:

- The design co-ordination process: This process was responsible for the design of the products requested by the customer and the design of the processes required to manufacture these products.
- The manufacturing process: This process was responsible for the production of products that met the specifications obtained from the design co-ordination process.
- The customer order fulfillment process: This process was responsible for fulfi~ling aIl orders received from the customers.

- The vendor supply process: This process was responsible for identiffig and supplying the materials required by the mantiacturing process.
- The co-engineering process: This process was responsible for the provision of suppIier design expertise to the product and process designs produced during the design co-ordination process.

The elements on the manufacturing typology axis were derived from Figure 4. This diagram partitions manufacturing typo~ogies into four types: Make to Stock @lTS), Assemble to Order (ATO), Make to Order (MTO) and Engineer to Order {ETO). The differentiation of the four was based on the point in manufacturing at which a product is firmly committed to a particular order. Thus in a Make-to Stock environment the goods are manufactured in the belief that a market will exist for them. A stock of finished products are maintained and orders are filled from this. In an Assemble to Order environment a stock of semi-finished products is maintained and when an order is received for a particular configuration, the relevant sub-assemblies are assembled together. In a Make to Order environment, a stock of standard components are maintained. When an order is received for a particular design, it is manufactured from these components . In an Engineer to Order environment, each order results in a new product being designed so that materials are committed to a particular order from the raw materials stage onwards.

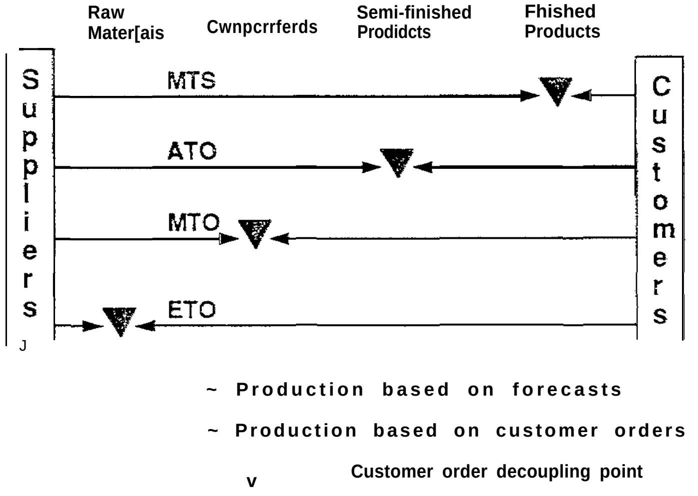

Figure 4: Customer Order Decoupling Point.

The elements on the competitive dimension *axis are* based on the five aspects on which a company can compete, narneIy [31:

o Time.

e cost.

. Quality.

e Flexibility.

~ Environment.

The function of the AMBIT13 cube was the eventual translation of the CSFS and SPIS into measures of manufacturing performance (MOMPS).

Generic MOW **map**

The generic MOMP map represented the decomposition of the identified SPIS (based on the **CSFS) into MOMPS.** The individual MOMPS were then combined to form a MOMP Map (see Figure 5], A MOMP Map was a partial model consisting of one or more "mini-cubes", each of which were defined by a single macro measure of performance (e.g. time), a single business process (e.g. design co-ordination process) and a particular part of the manufacturing typology (e.g. **ETO).** Each "mini-cube" consisted of' one S?1 and its associated MOMP hierarchy. The MOMP map therefore consisted of a number of SPUMOMP hierarchies, normalised to remove redundancy and combined into a single map consisting of a number of SPIS (one for each "mini-cube") and their associated MOMPS. At this stage, the MOM.P map represented a partial or uninstantiated model of the enterprise and must be customised to become a specific model

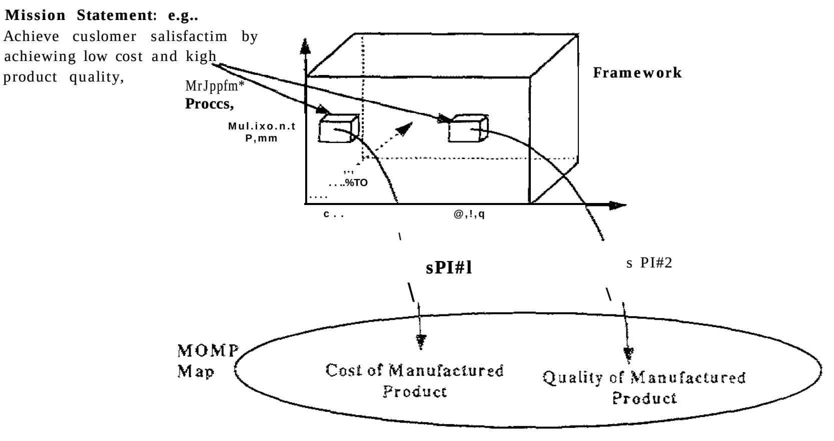

Figure 5: Derivation of MOMP Maps.

Customised MOMP map

The customised MOMP map represented a MOMP map which had been structurally customised (by modi&ing/editing the MOMP map) to describe the organisation that was using it.

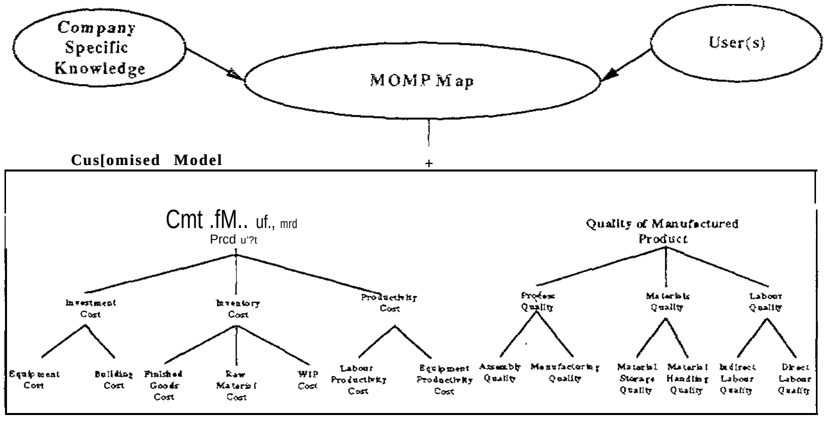

Figure 6: Customisation of the MOMI? Map.

Specific MOMI? map
The specific MOMP map referred to the instantiation of the customised MOMP Map (see Figure 6) by assigning current, benchmark and tzu-get values to the individual performance measures appropriate to the organisation under study. This "specific MOMP map" would be used later by the anaIysis tools to assess the impact on this MOMP map of introducing a new technology/programme.

3.2 AMBITE - Stage 11

Stage II of the AM131TE process involved the development of a qualitative model which described a particular technology or programme. Two separate models were constructed, one for Interconnect Technology and the other for Concurrent Engineering. The model contained knowledge on a particular technology/programme and the relationship between the pieces of knowledge.

The model (Interconnect Technology} developed was a representation of the relationships between the lower, more operational regions of manufacturing strategy and the upper regions of manufacturing strategy in terms of Interconnect Technology [4]. It indicated the effects of changes made at a lower level on goals at the upper level of manufacturing strategy and thereby provided a framework for making technological decisions. The model included sufficient technical details to give an accurate representation of the electronics technologies and their effects, but included only issues understandable by the management team and relevant to the decision to be made. Essenti.alIy, the model presented the relationship between technological issues and the upper levek of manufacturing strategy from a perspective familiar to a manager. Otherwise, the model would defeat its purpose by describing the Interconnect Technology domain in terms more appropriate to an engineer, resuIting in the manager becoming lost in technical detail, some of which may not be understandable.

Essentially, Stage H of the AMBITE framework was primarily concerned with the identification of Key Technology Variables (KTVS}, in the case of Interconnect Technology, and Key Programme Variables (KPVS). in the case of Concurrent Engineering. Effectively, within this stage the relationships between the KTVsiKPVs were mapped into a generic MOMP modeI, which was subsequently customised to reflect the customised MOMP map (generated during Stage 1). As the Interconnect Technology model is described in this paper, then KTVS are used to describe the model.

During the AMBITE project, models were developed for a specific programme and technology. The detailed information in these models was provided by the industrial endorsers and this information can be seen in the specific modek that have been developed. In this paper, the focus is on Interconnect Technology and the models described here refer to the technology model that was developed'.

Key Technology Variables (KTVS)
The knowledge in the Interconnect Technology model was represented using key technology variables (KTVS). A key technology variable may be defined as a key feature that is common to all assembly technologies, and is part of a set of KTVS which differentiates one assembly technology from another [4]. Each assembly

' Information on the Concurrent Engineering programme models can be obtained from the second yearly report (Report No. 5: AMBITE 12 Monthly Report 01/01/95 - 31/'12/95}.

technology has a specific value or range of values for each KTV. The variables are termed “key” in that they me characteristic variables of' the electronics manufacturing industry and can be identified as the main technological drivers in determining a particular organisation's corporate success. In Figure 1, Stage II is represented pictorially as a set of steps, name~y:

- Collect Knowledge about ProgrammeiTechnology
- DeveIop Generic Programme/Technology Mode]
- Develop Specific Model

Each of these steps are now briefly explained.

Collect Knowledge about Programme/Techrnology

ffiowIedge about the technology or programme represented the knowledge of that area as captured through literature reviews and industry targeted questionnaires. Interconnect Technology referred to the manufacturing technology which used to provide interconnection between various components on an interconnecting substrate in order to provide a desired fimctionalit y. Examples of Interconnect Technology include PTH (plated through hole), SMT (sm+ace mount technology), IV? [fine pitch), COB (chip on board) and hfChl (mu~tic~lp module).

Develop Generic l?rogramme/Techno@y Model

The generic programme[technology model was created when knowledge concerning the selected programme~tec-hnology was structured into a generic model by mapping the KTVS (Key Technology V=iables) to the MOMPS on the bottom level of the generic M(IMP map **(as** identified in the generic MOMP map of Stage 1).

Develop Specific Model

This model was developed when the generic programmehechnology model was customised so that it became a specific model (whose MOMPS reflect the specific MOMP map) appropriate to the company under study. The customisation involved modifiing the re~ationships that exist. between performance measures and ako included instantiation of individual measures with values appropriate to the company.

Interconnect Technology Model Extracts

In figure 7, a piece of the Interconnect Technology model is shown. The model segment. shown, which is related to the Manufacturing business process, helped the manger to identify the technology variables impacting True Yield, which was a MOMP, and to understand how they impact this MOMP. True yield was a measure of First Pass Yield of PCJ3S from an assembly process. The module is illustrated by moving f%om the MOMP, First Pass Yie1d5 to a number of KTVS. First Pass Yield was a measure of the quali+y of the assembly process. It represented the number of finished PCBS that do not require rework or repair of any kind. This yield figure is determined by the yield of process of the assembly technology used to assemble the PCBS.

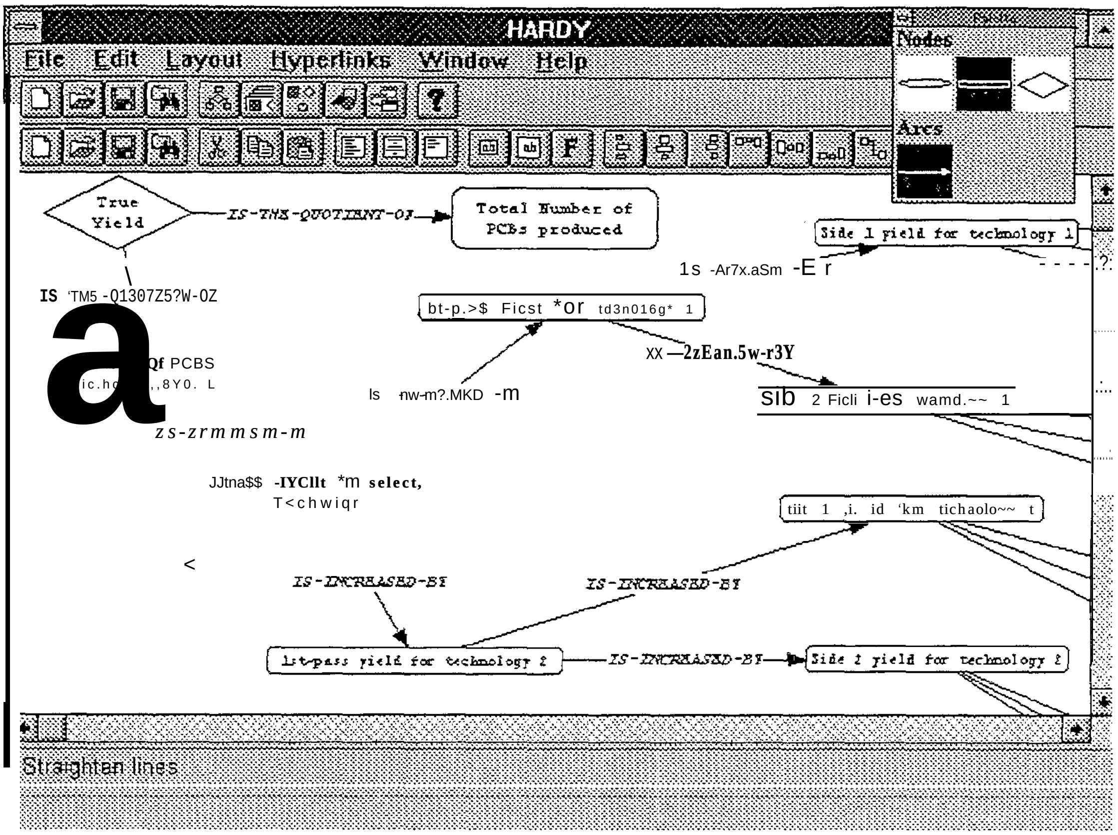

Figure 7: **Viewing First Pass Yield in terms of Primary Ted-moh@es ad. P(XI Sides [4]0**

Another segment of the Interconnect Technology model is shown in Figure 8. In this segment, the yield of Technology 1's process is recognised with respect to say, component type-1, as being determined by the quality of the each process step with respect to that component type. One of the process steps in electronics assembly was component placement. Figure 8 shows how the model related the quality at this step, with respect to component type-l, to the quality of the total Technology 1 process with respect to component type-1.

The performance of any technology's placement equipment with respect to quality of placement is a function of the capability of the machine and the potential for error during the placement process. Even though the placement equipment for the type- 1 component of a primary technology may be very capable, say in terms of accuracy, it does necessarily mean that it performs better with respect to quality in placement than a less accurate machine for type-1 components in another technology. For the less,, accurate machine in the other primary technology the potential for failure may be less and thus the accuracy is not critical. Therefore, the level of quality reached may be just as high as that achieved by an accurate machine in another technology, COB placement equipment is very accurate, but the potential for error during placement is very high. PTH placement equipment is not as accurate, but the potential for error during placement is lower. So one cannot say that the quality of placement is determined by placement accuracy or machine capability alone. It is a function of both machine capability and the potential for error in the placement process.

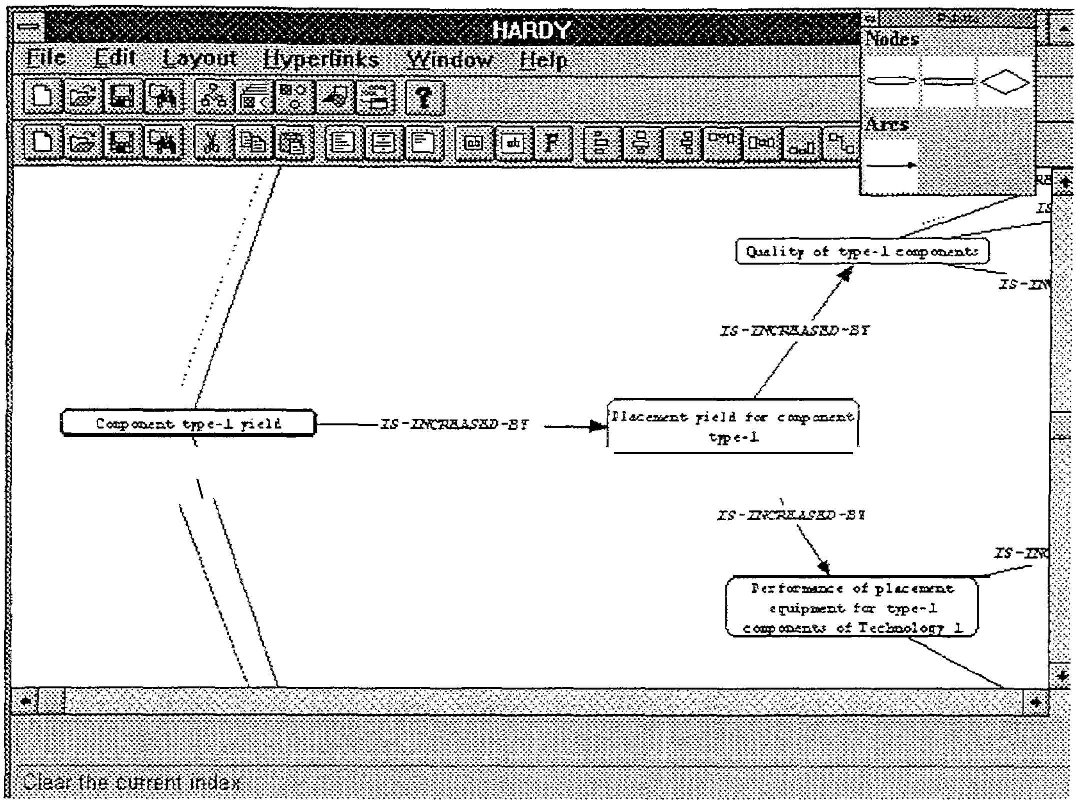

Figure 8: Viewing Yield for Component Type-1 in terms of Process Steps.

3.3 AMBITE - Stage HI

Stage HI of the AMBITE framework was concerned with the development of a set of analysis tools which can be used to anslyse the impacts of the specific technology model orI the specifk MOMI? map. This analysis resulted in the identification of a set of implementation issues that allowed senior management to assess the consequences of their decisions. 'The analysis tool developed must be able to reason using both qualitative and quantitative information. Typically, the quantitative data was obtained from the specific MOMP map while the qualitative data was obtained from the specific technology modeL

Stage III of the AMBITE framework was concerned with two specific objectives, namely:

1. the identification of a set of tools to capture and represent an individual organisation's understanding of the impact of the selected technology/programme on its business and
2. the analysis of the impact of a specifi~ technoiogylprogramme on the selected MOMPS and ultimately the SPIS.

In order to complete these objectives, a set of prototype analysis tools were developed. The three analysis took developed are as follows:

- **PROTIMA - A** tool which used to ardyse the specific model (developed in Stage H) and to assess its impact on the specific MOMP map (developed in Stage 1).

- **Case Based Ikasoning Tool - This tool.** used prior knowledge of specific cases to ascertain the likely consequences for the current case being analysed.
- **Time Cost Tool - This tool** examined various activities in a business process and calculated the time and cost effects of any changes made to this process.

The PROTIMA analysis tool is now described in more detail.

PROTIMA **Analysis Too1**

The PROTIMA analysis tool was a computer based tool which related the specific model to the specific MOMP map. The specific model was analysed using causal reasoning techniques, which showed the effect of the programmeltechnology on the MOMPS. Meanwhile, the specific MOMP map was analysed using the AHP (Analytic Hierarchy Process - a tool designed to facilitate quantitative and quahtative decision making) [8] method which produced a ranking of-the MC)MPS in terms of their importance to the organisation. Note that causal reasoning tools can accommodate both quantitative and qualitative knowledge

One of the analysis tools deve~opeci was a tool called PRCYHMA fZbgwmmf&chnology Implementation Analyser) [7]. This tool was used to analyse the specific technology model and to assess its impact on the specific MOMP map. The results of this analysis are then presented to the user. The analysis of the specific technology model, the specific MOMP map and the results of the analysis are now explained in some detaiL

Analysis of the specific technology model

The analysis of the specific model was based on the methodology of KASPER as developed by Jackson [5] [6]. The fact that a causal relationship exists between two schemata tells us the nature of the of the influence that the root has upon the leaf e.g. increase. However, it tells us nothing about the extent of that influence, or how it varies with changes *in* the root schema. To overcome this deficiency, each causal relationship was defined by a Causal Effect (CE) function. The function consisted of a graph, drawn over a scale ranging down from -1.0 to 1.0 for both the X and Y axes. The X-axis represented the change in the root schema while the Y-axis represented the change in the leaf schema caused by the root schema. The point -1.0 represented the maximum foreseeable change that the user believed was in the negative direction. The point 0.0 represented the relationship between the root schema and the leaf schema prior to either one changing. The point +1.0 was the maximum foreseeable change the user felt was possible in the positive direction. The positive direction was defined to be the direction of desirable change for a given schema, A sample CE and CF function graphs (negative part) are shown in Figure 9. t

Other values are also used to build a profile if how particular schemas were affected by changes that occurred in their root schemas. The values included [5]:

- **Independent Causal Effect (ICE) -** the value of the GE function for a leaf schema at any particular moment in time.
- **Degree of Confidence (DOC) -** a value indicating the strength of the users belief in the ICE value.

- **Aggregated Causal Effect (ACE) - as** a leaf schema can be afYected by more than one root schema, this value gave an indication of the true impact on the leaf schema.
- **Confidence Function (CF) - a** function which described the DOC value for every possible ICE value.

A set of these values can be obtained for each schema in the model.

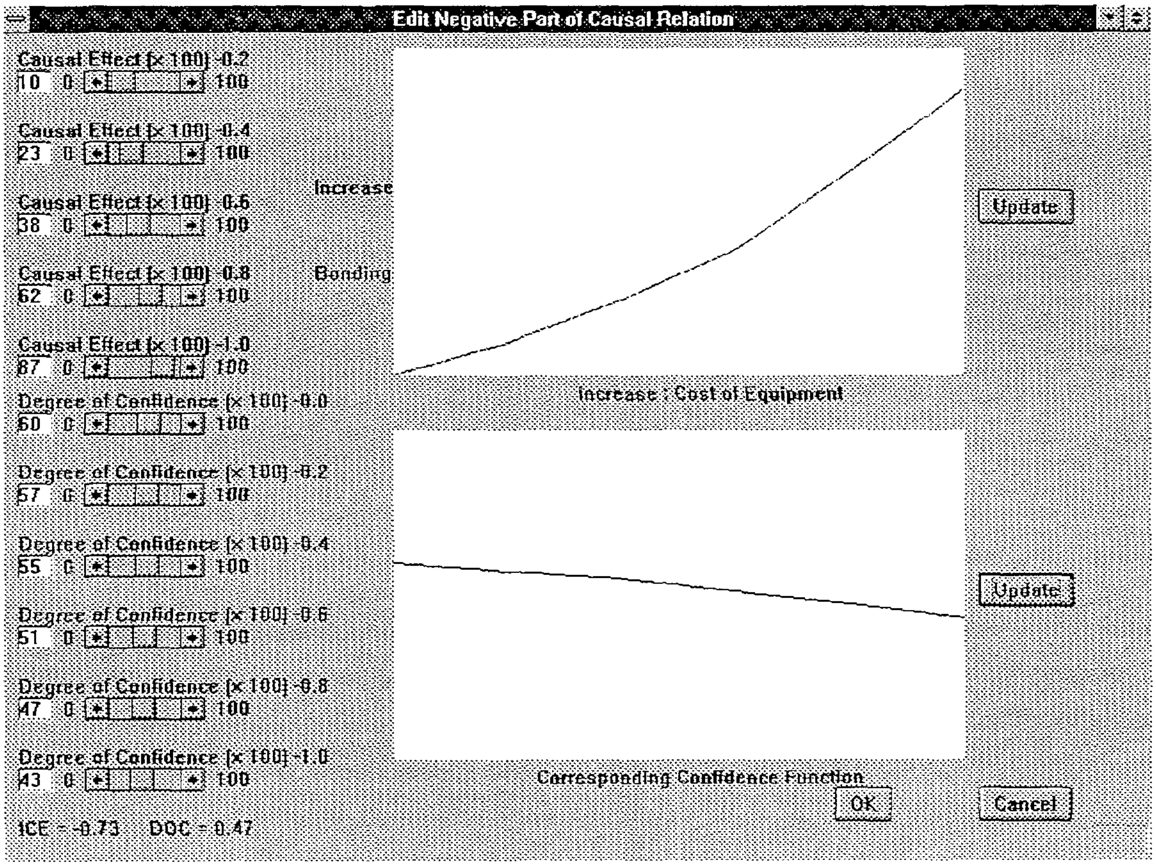

Figure 9: Initial CE and CF functions [71.

Analysis of the specific MOMP map

The analysis of the specific MOMP map was based on the Analytic Hierarchy Process (AHP) [8]. Some alterations were made to the technique, as there were some differences between the structure of a MOMP map and the structure of the type of hierarchy for which A.HP was designed [7].

The most glaring difference was that the stand~d AHP was designed to rank competing alternatives while the analysis of the MOMP map sought to rate different MOMPS, not as alternatives to each other, but in terms of their importance to the companies SPIS. However, if AHP is examined in order to rank the competing alternatives, the goal was first broken down into sub-goals, which were then rated in terms of their importance to the goaL These sub-goals were then further broken down, the elements of the new level again being compared with respect to their 'parent'. All of this was paralleled in the speciilc MOMP map with the decomposition from SPI down through MOMPs which were very general, all the way down to very specific MOMPS. The MOMPS can be compared to each other with respect to their 'parent' MOMP. The differences arose at the very bottom level, where the .AI-IP had a set of alternatives which were ranked with respect to every single element on the next highest level. This was missing in the specific MOMP map. With the AHP, the weighting of an alternative was arrived at by summing the product of the contribution of each of the elements on the next highest level by the relative importance of that element.

However, by having an AHP-type structure, but without having the bottom Jevel of alternatives, AHP analysis was used to calculate the importance of elements of that structure with respect to the overall goal. This meant that a speci& MONIP map was analysed in order to reveal the relative importance's of the bottom row MOMPS with respect to the overalI goal.

The framework of PROTIMA sought to link the implementation of new technology/programmed to a set of SPIS by way of a set of MOMPS common to both. The KASPER analysis of the specific model served to show the effect of the new technology/programme on the bottom level MOMPS while the AFIP-type analysis illustrated the relative importance of those MOMPS. Taken together, they formed a means of gauging the major strategic implications of the introduction of a new technology/programme into a manufacturing operation.

PROTIMA was developing using a range of software tools, namely:

- * CLIPS [9] - an expert system tool which provided an environment within which expert systems were developed and delivered.
- e WXCIJPS [10] - allowed CLIPS programmers to write portable graphical programs which ran under Windows 3.1 and X Windows.
- - HARDY [11] - a diagraming tool that was used for any type of diagram and could be programmed to allow the user to analyse the diagram that they had designed.

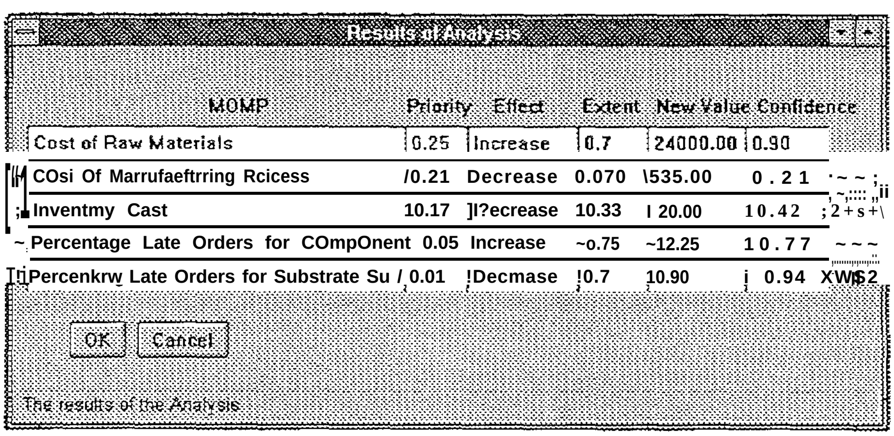

Figure 10: The results of the analysis [12].

Issues for implementation

The results of the analysis tool was a set of implementation issues. For example, for each MOMP there was a description of the current value, the desired value and the manner in which the MOMP was influenced should the technology or programme be implemented. A window showing the resuh.s of a sample PROTIMA analysis is shown in Figure 10 [12].

As Figure 10, illustrates, the results of the PROTIMA analysis were not a straight forward yes/no answer as to whether the organisation should imp~ement the technology/programme. The user must interpret these results and draw their own conclusions. For example, the "Cost of Raw Materials" MOMP was relatively important (priority = 0.25) and the results indicated that the implementation of the technology in question would increase its value to .S24,000. The "Cost of Manufacturing Process" MOMP was also important (priority = 0.21) but the decrease in it's value was only S535. The "Percentage Late Orders for Component Supplies" MOMP was relatively unimportant (priority = 0.05] but it was increased by 12.25% which is a significant increase. From the above points, it was likely that the user would view these changes in the MOMPS as undesirable and hence would reject. the proposal for the implementation of the technology in question [12].

4.0 Results

Three specific results were obtained fiorn this project. The first major result was an approach which allowed the translation of the business goals of a manufacturing enterprise into a set of operational level performance measures. The second major result of this project was the development of a set of semantic models for Interconnect Technology and Concurrent Engineering. This models were populated with specific data supplied by the industrial endorsers. The third major result was the developmefit of a set of analysis tools. These analysis tools provided a means of assessing the consequences of introducing a new technologyiprogramme on the performance measures of a company and ultimately on its business goais. Each of these results were closely linked to each of the stages described in the AM131TE Framework.

5.0 Conclusions

Senior management are responsible for making strategic decisions for their companies. These managers tend to have a good breadth of knowledge but lack the detailed technicaI knowledge to understand how their decisions wilI affect the performance of the company. Employees at lower levels in the company tend to have detailed knowledge about particular areas. In the case of Interconnect Technology, process/design/manufacturing engineers would have the required knowledge depth.

Senior management also tend to focus on long term goals and performance measures. The decisions they make are made in an attempt to meet their long terms goals. However, all strategic decisions usually affect lower level, short term performance measures which are used as the basis for assessing the performance of the manufacturing enterprise oi a daily, weekly or monthly basis.

Very few tools andlor techniques exist that can be used to assess the implications for a manufacturing enterprise (or any other business) of the strategic decisions that the company makes. Any such took or techniques would need to combine the strategic thinking of the senior managers and the detailed knowledge of domain experts within the company. The tools or techniques would also need to identifi the affect that the strategic decisions would have on short-term manufacturing performance measures. The tool(s) developed would also need to be able to handle both qualitative and quantitative data and to assess the assess the implications of one on the other. The question of whether or not a new manufacturing technology/programme should be taken up is more likely to be answered positively if the likely impacts of such a decision should be quantified.

In this paper, the research work undertaken on the AMBITE project was described. The objective of this project was to develop a set of took and techniques that would allow senior managers to assess the impacts of strategic decision making on the manufacturing performance of their companies. The tooIs and techniques developed as part of this project were successfully tested by senior managers horn a range of krge European multi-national companies.

Acknowledgements

The authors would like to thank the European Union for their funding of the AM131TE project (Contract No.: BRE2-0533) through the BRITE-EURAM progrsm. Thanks is also due to the other members of the AM131TE consortium (academic and industrial) for the work they have done on the project.

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