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A Course on Competitive Concurrent Engineering within a CIM Environment*

PETER A. M. VAN KOLLENBURG†
GEORGE PUNT‡

† Department of Electrical and Electronic Engineering and ‡ Department of Business Engineering, Hogeschool Eindhoven, The Netherlands, PO Box 347, 5600 AH Eindhoven.

The Department of Electrical Engineering of the Hogeschool Eindhoven offers a B.Eng. level course in computer-integrated manufacturing of electronic systems (E-CIM). In this course, students are trained in applying computer-integrated facilities in order to bring down the 'time to market' of electronic products. Another important aspect is to train the students in the use of the principles of concurrent engineering, i.e. working closely together in a team consisting of individuals from different disciplines. In this way we aim at reaching that one and only goal: being more competitive! From research on five courses (65 students) we found that the 'time to market' was indeed short, but the cost price of the developed products was rather high and more diverse than expected. In order to improve on these aspects, we introduced the so-called 'factory cost price indicator', a software tool that integrates group technology with an 'experienced database' and an evaluation of the actual cost price. This tool, which is already in an early stage of development, enables inexperienced designers to get an adequate indication of the total costs of the product under development. In combination with concurrent engineering, we aim at educating multi-disciplinary oriented and communicative designers, who are eager to transform their 'products of mind' into competitive commercial products.

INTRODUCTION

TECHNICAL education is commonly based on specialized courses. In such a course a teacher may operate independently from colleagues or even from other courses. As a result technical students are trained to solve (technical) problems only in relation to a given course. Only rarely are students educated in solving a problem in a broader and multidisciplinary perspective. Concurrent engineering (CE) stands for pulling down the walls between the departments [1]. In doing so, teachers must co-operate and communicate with teachers of other disciplines: this yields more work (meetings), more planning and makes the assessment of the students' progress less easy. Thus it is not surprising that CE is not yet common in education.

When we started computer-integrated manufacturing (CIM) courses in 1988 we focused on very specific and monodisciplinary courses. In the center was the 'product creation process' (PCP) from design to manufacturing. But we also introduced an additional integrative course named 'Business Automation' based upon CE. In this paper we highlight this integrative course and the future developments we have in mind; firstly we start with the introduction of our CIM environment.

THE CIM ENVIRONMENT

At the Hogeschool Eindhoven we have created a 'real-life CIM enterprise'. Obviously one may teach what CIM stands for in theory; but nothing can compete with doing it yourself and discovering what goes wrong and with solving such problems regarding CIM activities. We created the CIM enterprise based upon three different departments:

1. A design department for electronic products, including engineering (the CAD department).
2. A production facility for electronic products (the CAM department).
3. A logistic department (the CAL department).

Each department is, in fact, a laboratory connected to a specific course (monodisciplinary). The integrative course mentioned above involves all departments in order to let the students create an electronic product. The hardware and software of the CIM enterprise supports the students in decision making during their product-creation process. This supporting involves supplying the relevant and correct information to the right place and in the right time, and this function is done by the so-called CIM Database (CDB). In Fig. 1 the information flow of the enterprise is depicted.

During the design process (CAD) the designer may check whether he/she is applying components and production machines that are 'known' in the enterprise. A report will be sent from the CDB stating whether or not this is the case. If the design

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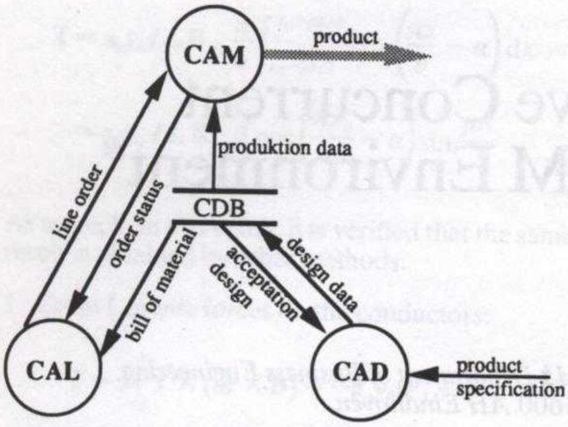

Fig. 1. Data flow CIM enterprise.

is accepted by CDB, the Bill of Material (BOM) is sent to the logistics department and production data is sent to the manufacturing department. At the time the product should be set in production, the logistics department sends a line order to the manufacturing department. During and after the manufacturing of the required products there is an information flow from manufacturing to CAL about the status of the order (e.g. how many ordered products have been manufactured, how many are discarded and how many are passed). All this information is available on each computer in line because they are interconnected via Ethernet.

To make this idea more alive, we firstly present a short overview on the hardware and software as used in the different laboratories:

- CAL utilizes a Philips P9050 multi-user system with 14 monitors. We apply a logistic software tool for production control developed by BAAN International™
- CAD includes 12 Apollo™ 3000 workstations with Silvar Lisco™ design software for schematic entry and layout of printed circuit boards (PCBs).
- CDB is a software tool especially developed for production preparation and is running on a VAX computer that is positioned in the centre.
- CAM is a production line for assembling PCBs (see Fig. 2).

After the PCB has entered the system, barcode readers pass information to the line controller (a VAX computer) where the PCB is located. The line controller knows about the routing of the PCB and, via a conveyor belt, guides the PCB to the correct placement machine required for that product (surface mounted devices on the AUREL™ placement and wire components on the ROYONIC™ light pen table). All information for placement is generated by the CAD system. After soldering with the SOLTEC™ industrial solder machine, the completed PCB is functionally tested on an automatic test configuration. A repair station is not 'in line' with the other equipment; it receives the test result of the product under repair from the test table via a printout that is automatically generated by the test program.

THE CURRENT INTEGRATIVE COURSE

This integrative course is being developed around the principles of concurrent engineering. Important items are (i) a multi-disciplinary team, (ii) the product creation process (PCP), (iii) a project-driven development, (iv) the CIM system and (v) the 'experience database'.

Our first aim is to shorten the 'time to market'; there should then be no iterations in the development process. This is only possible when all persons involved in the PCP stick to the same agreements; this necessitates early involvement and integration of departments into a team, responsible for the total product development. In our course we simulate such an organization: a class of students (in their graduation year) is split up in teams of five persons each. Each member of the team chooses a task, and a responsibility which corresponds best with his/her experience and interests. We then get a multi-functional team as

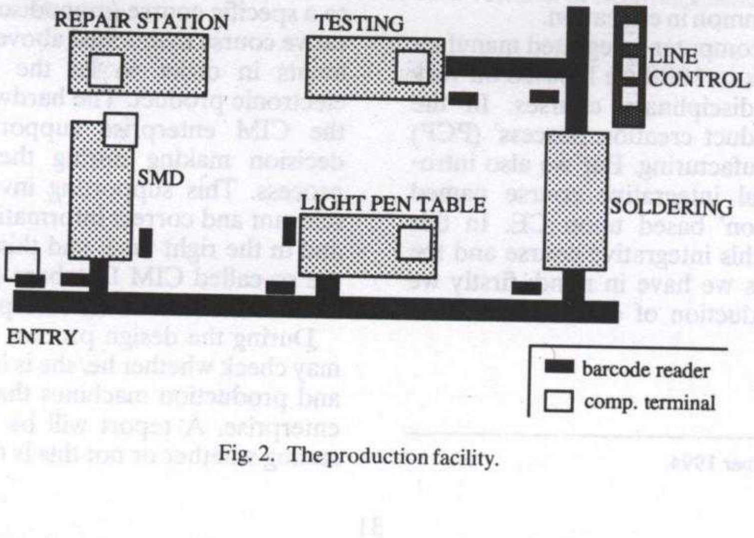

Fig. 2. The production facility.

follows: (i) marketing manager, (ii) Development manager; (iii) production manager, (iv) logistics manager and (v) quality manager. This team carries on through the total PCP, and so the awareness of personal influence on the success of a design as a product will grow for each individual team member.

By giving the students responsibility and power, they learn how to communicate to solve problems within a group and how to delegate tasks; they furthermore gain insight into the importance of teamwork to reach a goal; finally, a natural interest in other disciplines is fostered.

Traditionally, manufacturing, test, quality and service organizations hardly see a design until it has been virtually completed [1]. Rather than working serially, CE aims at working in parallel for the total PCP as much as possible. However, milestone meetings during the project, on which the state of the development is discussed, are still required. In our course we split up the PCP into five timeframes: (i) product start, (ii) specification, (iii) design, (iv) engineering and (v) production. Each timeframe expires with a milestone meeting. After discussing the checklist, each meeting is completed with a milestone release (see Fig. 3).

After such a milestone meeting, each team member knows on which points and why the product has been modified (recall that ideally, there are no iterations nor changes at all!). The development of the product will be stopped here if no agreement is reached among all team members.

Nowadays there is hardly doubt as to the importance of training students to work with automated design and production systems. At the Hogeschool Eindhoven we developed such a computerized integrated manufacturing system for electronic engineers (see above). The fact that all these systems are integrated certainly speeds up the PCP.

An important tool of the CIM system is the so-called 'experience database'. This database is used as a guideline for project planning. It contains information on all activities required to carry out a project as a whole, such as information on hardware, software, tools or even literature. This database is being built up over the years as students carry out such projects.

EXPERIENCES WITH THE CURRENT COURSE

Over the past five years, more than 100 students have participated in this course. For evaluation purposes, we used the results of 13 groups of five students, each group carrying out the same design: a coded lock. These data constitute a unique database to quantify to some extent the benefits of a concurrent engineering course. There are four main conclusions:

1. There was a relatively short 'time to market' (15 weeks for a product of medium complexity). Apparently CE allows monitoring and control of the development progress.
2. The cost price of the products of the various groups shows a large variation (see Fig. 4). Despite of the same initial specifications, the final designs of the groups and the corresponding prices differ greatly. Possible causes are differences in final functionality, and in the techniques, materials and production processes that were used.
3. The cost price did not seem to stabilize during the design and production process. No doubt

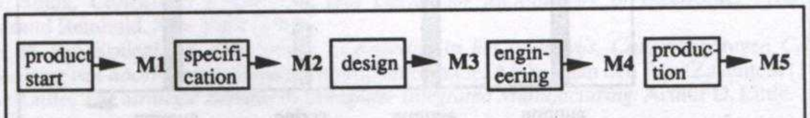

Fig. 3. The PCP split up into subsections.

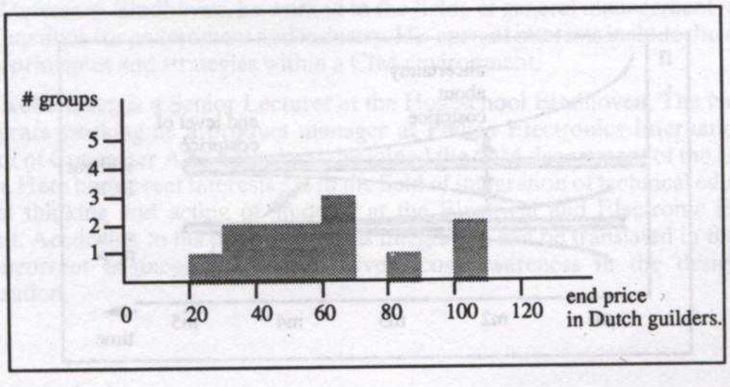

Fig. 4. Cost price of 13 design groups on the same task.

the teams are eager to produce low-cost designs; however, they may show inadequate insight into financial consequences of their decisions. often, early mistakes have to be set right afterwards by means of expensive solutions.
4. New incoming groups did not reach a better (lower) cost price over the years (Fig. 5). Apparently they lack the experiences of previous students (a learning curve).

In general we have the impression that our students are not adequately aware of aspects of cost-effectiveness but rather are fully oriented towards technical problem solving. On the other hand, the CIM environment does not currently supply them with the necessary tools for cost control.

THE CURRENT COURSE EXTENDED WITH COST PRICE MONITORING

In our opinion, the control of the cost price during PCP is of great importance. Turino [1] even states: 'the purpose of Concurrent Engineering is to make sure that the early design decisions can minimize the overall product costs of the life of the product'. This is exactly what we want to teach our students. Therefore we decided to extend the current course starting from the following points of view:

1. Students have to experience the importance of solid cost control themselves.
2. Tools for improved control of costs are mandatory; such tools should be easy to use, even by inexperienced designers.
3. The 'experience database should be etended with cost information from previous development teams; this gives the new teams the opportunity to hop on the bandwagon of the learning curve.

In order to teach our students how to be really competitive regarding the control of both 'time to market' and costs, we introduced a new software tool, the so-called 'factory cost price indicator' (the FCP indicator). This tool enables the designer to calculate the cost price of a product under development on hand, at any time during the design process. The FCP indicator integrates so-called 'group technology' with an extended 'experience database' (containing design rules for costs) and with a hands on evaluation of cost price. For calculating the cost price, the FCP indicator requests data from the logistic system. The tool gets its information from previous cost experiences.

When using the FCP indicator, we expect to see a cost price that is readily predictable at an early phase of the PCP and that will show a fast convergence to a lower level in the end (Fig. 6).

Over the product creation process, the FCP indicator is used as follows:

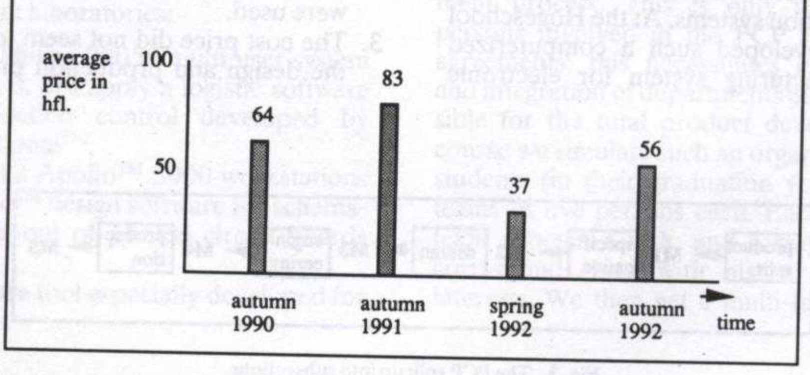

Fig. 5. Time course of the average cost price.

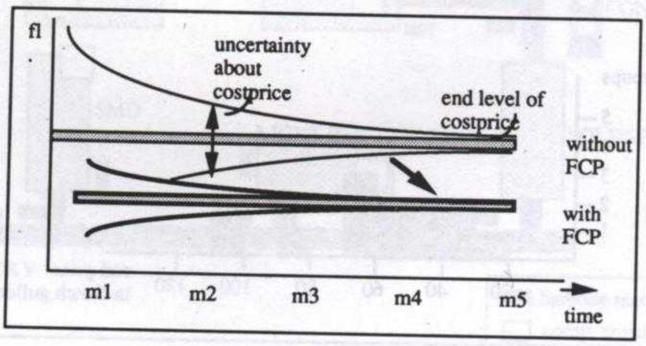

Fig. 6. Effects of FCP.

1. In the product start-up phase, the cost price cannot be calculated. At best, a desired cost price can be set based upon marketing research.
2. In the specification phase, the FCP indicator is used for an initial rough calculation of cost price. In this phase, detailed calculation is impossible, since the components are still unknown. Research on new products shows that 80% of the products had already been designed before [5]. Instead of reinventing the wheel, the designer is encouraged to use or modify existing designs. The designer can use the methodology of 'group technology' in which previous products have been classified according to functionality [2].
3. In the design phase, the FCP is used to define the remaining novel portion (20%) of a design. In this phase, there are several technical solutions to a problem. The FCP gives the designer hands on information on costs of each solution, not only on prices of material but also on a factory level. The designer must decide on both technical and factory cost price arguments. The design rules that are already contained in the database constitute guidelines for technical feasibility. Using the FCP, these design rules are now extended with new guidelines for low-cost design.
4. In the enginering phase, all parts and steps necessary for manufacturing steps are known. Thus a detailed cost price calculation is possible in this phase. The FCP indicator, however, enables designers to do the calculation themselves in a quick and easy manner.

RESULTS AND FUTURE EXPECTATIONS

We presented a plan to extend a course based upon the principles of concurrent engineering with tools for easy monitoring and control of cost price—the so-called FCP indicator. Still under discussion is how to build the FCP database and where to position the database in the overall CIM system. We expect that this tool will contribute to a lower cost price in the end. In addition, already in an early phase of design and development, it gives the designer a more accurate estimation of the final cost price of the product under development. The better the information and control, the better justified will be the decisions that are made during the PCP, e.g. on whether or not to continue the development of a product. In this way, expensive design capacity will not be wasted on a product which eventually turns out to be far too expensive. It also prevents a product from being terminated, during the design process, based upon overly pessimistic cost price arguments, when it could potentially have been a winner. It is our philosophy that by raising the awareness of cost control, students will learn to improve competitiveness with concurrent engineering. It is our belief that in this way we can educate interdisciplinary oriented and communicative designers, who are eager to transform their 'technical products of mind' into competitive commercial products.

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George Punt is a Senior Lecturer at the Hogeschool Eindhoven, The Netherlands, working in the Department of Business Engineering. After his graduating in business engineering at the Technical University Eindhoven, he worked in the fields of general management and finance in several functions for government and industry. His current interests include the application of business principles and strategies within a CIM environment.

Peter van Kollenburg is a Senior Lecturer at the Hogeschool Eindhoven, The Netherlands. After six years working as a product manager at Philips Electronics International in the Department of Consumer Audio Products, he joined the CIM department of the Hogeschool Eindhoven. Here his current interests are in the field of integration of technical education and commercial thinking and acting of students at the Electrical and Electronic Engineering Department. According to his philosophy, this integration can be translated in the following words: concurrent engineering, custom driven, cost awareness in the design process, computerization.