The current issue and full text archive of this journal is available at
www.emeraldinsight.com/1463-5771.htm

Best practices of collaboration between university and industrial SMEs

P. Peças and E. Henriques
Technology and Management Group, Department of Mechanical Engineering, Instituto Superior Técnico, Lisboa, Portugal

Abstract

Purpose – The purpose of this paper is to contribute to the implementation of best practices of collaboration between university and industrial small- and medium-sized enterprises (SMEs).

Design/methodology/approach – This paper presents the experience carried on by a university group fostering the collaboration with SME companies involving young engineering students and researchers in projects designed for the resolution of real industrial problems. A collaboration model is proposed and described. Four real case studies are presented.

Findings – The purposed model promotes the involvement of the young engineers with authentic industrial experiences, enables the build-up of their practical framework and encourages their entrepreneurial growth. It also promotes the innovation process in SME companies through the close collaboration with universities.

Practical implications – The collaboration between universities and SME companies should be based on a small projects base. These projects must be focus in localized and specific problematic areas in the industrial companies, where the potential of improvement and innovation is large, must diagnose the problematic situation and propose new and efficient solutions supported by technical/scientific methodologies. The involvement of managers and collaborators of SME companies and the clearly definition of their roles in the project are fundamental issues for the collaboration success.

Originality/value – The model presented in this paper describes an innovative step-by-step procedure, easy to be implemented by the universities. It emphasises the impact of some details during the collaboration process that enhance the success potential of university-SME companies' projects, the quality of the research work produced and the quality of young future engineers training. It also fits with the SME companies' demands of a mix of structured knowledge and empirical experience.

Keywords Universities, Small to medium-sized enterprises, Lean production, Best practice, Partnership, Portugal

Paper type Research paper

Introduction

Manufacturing has changed radically over the course of the last 20 years. Moreover, the only thing certain in the future is the change acceleration in the manufacturing domains. New products and processes are and will be foster by the emergence of new manufacturing technologies, stimulated by intense competition. As complement, new management and labour practices, organizational structures and decision-making methods will emerge (NRC, 1998; Tavares, 2000). With regard to recent studies concerning the manufacturing challenges for the following decades a critical step will be the development of an underlying technical foundation through research performed by industry, academia, and government institutions (NRC, 1998; Mateus, 2000). Taking advantage of the synergies of these three research actors, manufacturers will fulfil

Benchmarking: An International Journal
Vol. 13 No. 1/2, 2006
pp. 54-67

1463-5771
DOI 10.1108/14635770610644574

the gap between current practices and the vision of manufacturing in 2020 by achieving concurrence in all operations, by integrating human and technical resources to enhance work-force performance and satisfaction and by "instantaneously" transform information gathered from a vast array of sources into useful knowledge to support effective decision-making processes (Alazmi and Zairi, 2003; Cahill, 2001).

Several authors identified the existence of barriers on the way to accomplish the referred challenges. Despite the dynamic increasing of the technological innovation processes between academia and industry the revenues of this collaboration are still very small relative to university research budgets (Graff *et al.*, 2002). Following Harmon *et al.* (1997), university transfer agencies intend to facilitate technology transfer but they give more emphasis on disseminating resources and competences rather than providing assistance in network building and relationship marketing efforts. In accordance with the formers Murphy (1993) states that the expansion of higher education has a low impact in the countries economy due mainly to the inadequacy of the technology transfer policies/methodologies. Liyanage and Mitchell (1994) refer that collaboration between academia and industry remains dependent upon the cultural, organizational and management characteristics of the partners engaged in the cooperative activity. Therefore, the strategies used to establish strong and long-term relationships between the university and industry must be adapted to the intrinsic characteristics of the organizations involved in the process. Santoro and Chakrabarti (2001) identified clear differences between the strategies that are used by the large companies to perform research and development projects and the strategies that must be used to promote the involvement of traditional small- and medium-sized enterprises (SMEs) in the innovation process.

With a core of highly skilled personnel, the large manufacturing organizations have the ability to understand the potential interest of the resources and competences disseminated by the university agencies (Santoro and Chakrabarti (2001); Harmon *et al.*, 1997). Additionally, the building of huge projects is facilitated either through financing by governmental institutions because of their social and economical impacts, or through the involvement of large academia means – the last ones always seeking basic research projects for papers publication (Todd *et al.*, 2001). Furthermore, these organizations possess strong internal research and innovation groups, so it is expected that will overcome the referred challenges (Mesquita *et al.*, 2000).

Nevertheless, for SMEs it will be difficult to overcome those huge challenges mainly due to the lack of internal human resources and to its traditional culture of poor investment in education and training (Matlay and Hyland, 1999). The SMEs have specific needs, usually more technological and/or organisational based (Mesquita *et al.*, 2000). So, SME are manly interested in using their relationships with university to address specific needs, which are nuclear to their business performance (Santoro and Chakrabarti, 2001). Actually, the few successful cases involving SMEs in innovation processes with academia are based on short-term agreements and involve small amounts of financial resources. Such relationships are generally driven to support small risk applied research with results that can be exploited in the immediate future (Mesquita *et al.*, 2000; Tavares, 2000). The university strategy fostering the involvement of SMEs with academia must have an interpersonal approach rather than formal (Demain, 2001). Also, SME owners and managers must be aware that the relationship with the university community is an important skill that they need to possess to enhance the opportunities to initiate a collaborative research project (Harmon *et al.*, 1997).

Keeble *et al.* (1999) give a strong emphasis on the SME-university networking and collaborative research to the collective and dynamic learning process of localized industrial regions. Accordingly, Jones-Evans *et al.* (1999) refer that this development could introduce particular benefits in small peripheral economies, which have demonstrated low levels of indigenous industrial technological development. As a result, universities could become increasingly important for the development of the local economies in smaller countries on the periphery of Europe.

Therefore, in a peripheral country like Portugal, where the manufacturing industry framework is comprised mainly by SME and where the number of micro companies is very significant (Mateus, 2000), a strong impulse in the innovation process is a key factor for the increase of competitiveness (Mesquita *et al.*, 2000).

Research methodology

The Industrial Management Group of the Mechanical Department of Instituto Superior Técnico (Technical University of Lisbon, Portugal) has developed intense partnerships with Portuguese manufacturing companies. Beside other activities, since 1998 this group has carried out more than 20 short duration projects with Portuguese SMEs. These projects with duration between 6 and 12 months were run by students of the final year of the engineering courses. The basic aim of the projects was to increase the productivity and competitiveness of the manufacturing companies through the implementation of dedicated "simple" engineering-based solutions.

Several approaches were used as regards to the projects management and to the methodologies for successful interaction between the companies and the university. Among the referred set of projects and mainly for the first ones some unsuccessful occurred in what concerns the fulfilment of the original objectives. The causes for these failures were identified, analysed and crosschecked with the successful projects. The approach has been optimised through an error-learning process, originating the increase of the success degree with the number of projects accomplished. The degree of success was measured qualitatively based mainly on the company involvement level, number of developed engineering-based solutions that achieved an implementation stage in the industrial environment and company requests for new project/collaboration.

The result of this process is the model described in this paper. In order to foster the validation of the model different projects developed in several industrial sectors are also presented. The described projects originated significant productivity improvements through the application of methodologies like SMED[1], discrete-event simulation and production re-engineering, among others. One must refer that a considerable number of projects have been extended and continue in a collaboration framework between academia, final year engineering students and industry, with results that are over the initial objective.

Model scope

In these short-duration projects the students must focus on a company critical problem. The students perform the diagnosis, followed by the development of potential solutions and impact estimation. The company collaborators, including management team, must be involved on the process from the early beginning. This practice assures the knowledge/technology transfer, the solutions feasibility and the personnel good will on the implementation phase. Taken advantage of student's irreverence, initiative, innovation spirit and work capacity, optimisation methodologies and systematic studies can be developed. The technological and scientific strictness is assured by the professor's coordination. The companies have the opportunity to see and discuss the diagnosis of their processes, to improve their process procedures, to have technological and economical feasibility studies, among others, at low cost, in a short term, and with results they can control. An additional benefit frequently observed is the contribution of this type of projects to the initiation of a continuous improvement culture inside the company.

The purposed model assures the response to the industry needs but also to the university researcher's need of papers publishing. The use of a scientific methodology is a demand referred on the model. So, the university students and faculty benefit from the interaction as they learn about the necessities and the improvement potential of the industry and gain real-life exposure to practical problem-solving experiences that they do not encounter in the classroom or in the laboratory.

The approach for collaborative projects between university and industrial companies based on the proposed model requires best practices from both: companies must be receptive to this way of know-how incorporation; universities must respect company secrecy and fulfil strictly the project aims and delivery time.

The success of this type of projects strongly emphasise the findings of other authors. The basic research is not always a necessary condition for innovation and actually innovation can occur in complex interactions schemes between many factors (Todd *et al.*, 2001; Conceição *et al.*, 1999). Demain (2001) refers that successful interaction between academia and SMEs must rely on frequent contact in an interpersonal based relation. Guthrie and Warda (2002) state that leadership is vital to innovation and top management must be involved in the innovation process with commitment and passion for change.

The conclusions withdraw from some comprehensive studies related with best practices of collaboration between university and SMEs are also fulfilled by the proposed model. Davenport *et al.* (1999) concluded that good will trust evolves and produces positive results if repeated collaborative relationships occur. This result was based on a study involving the development and implementation of a collaboration procedure to facilitate communication between university and New Zeland' SMEs. Sheather *et al.* (1993) applied an experimental learning theory model for cooperative education in Australia, with significant benefits for both industry and academia. Cooperative education increased the Australian industry overall competitiveness in global markets. Academia increased its knowledge and perception about the industrial application of their own theoretical models and the students were trained under industry-based scenarios, using real and industrial-useful case studies. Klofsten and Jones-Evans (1996) based on a study developed under a ten-year period involving European organizations, state that the collaboration between university and SMEs must rely on five factors. The purposed activities/projects must meet real needs, be ran by a core group and have a clear focus. The partners must have credibility and a close relationship.

So, instead of huge and/or international projects building, the local collaboration and partnership developed under this model can lead to continuously up-graded companies and increased university societal framing (professors, researchers and students). The collaboration between industrial companies and universities is a foundation for competitive societies and, simultaneously, a tool for continuous improvement of both organizations type (Lyu and Gunasekaran, 1993). Partnership with a variety of manufacturers illustrates that university can provide industry with practical knowledge and assist them within the processes of defining and implementing state-of-the-art solutions for their current problems (Sheather *et al.*, 1993).

Model description

The following described model comprises three phases: preparation, diagnosis and solutions development. In the preparation phase the university's member (from now on referred as professor) must establish contact with the industrial company top management. The objectives of the project should be collaboratively defined after a wide-ranging brainstorming concerning the company general requirements and professor's group expertises. It is critical for the project success to involve the company top management at this phase, in order to assure both the employees active involvement during the following phases and the matching between the project results and company expectations. The project to be built must be localized, e.g. focusing a workstation, a production cell, a small set of operations, etc. Trying to set up a complex project in order to answer to several company expectations at the same time will result in the project failure and/or in too long project duration, which is incompatible with the students' available time. If a company reveals expectations in several areas, then several separated projects should be designed and performed independently. Furthermore, if a company presents a complex and intricate problem it should be decomposed in several subprojects, with interfaces well defined, but with objectives and methodologies designed for a group of one or two students.

The professor can foreseen the work to be developed after company commitment and interest in a project to tackle a specific problem. So he should run an informal survey among the students in order to select an interested and psychological fitted one. The student must be aware of industrial project typical features (e.g. several trips and several time periods in the company, etc.), and also be prepared to deal with undercover opposition by some of the employees. Also, the professor should select more than one student (maximum three students) for projects needing higher levels of creativity and/or work effort.

The next step is the definition of the project tasks and intermediate milestones. The professor and the student(s), at the university side, and the head of product/production sector (including elements of his team if he wishes so), at the company side, should be involved in this step. The objectives of the defined tasks and the methodologies to apply must be very clear, in order to simplify the communication and to avoid higher levels of expectation than the ones withdrawal at the project end. This step is critical to the professor: he must assure that it will be possible to develop the project using structured, technical and up-to-date approaches and methodologies (e.g. Kanban, SMED[1], JIT[2], TQM[3], TPM[4], MRP[5], discrete event simulation, etc.), within the resources and time frame available.

The defined tasks and intermediate milestones should be submitted to the company top management for approval. Remarks and/or inputs coming from the top management should be taken into consideration, if the professor considers them relevant and appropriate in a learning and research context. It should not be forgotten that the project content must not only aim the reduction or the elimination of the company organisational and/or technical problems. It must allow the application of universal scientific- and/or technical-based methods and tools and must promote their incorporation as knowledge in the company.

After last step approval by both sides the project can start. The diagnosis phase (phase 1 in Figure 1) begins with the information gathering from the manufacturing system, work labour, product and process characteristics, etc. The students will lead this phase by collecting data and asking for inputs from the production/product responsible and from the technicians directly or indirectly involved.

Depending on the project type, these data can be qualitative and/or quantitative (e.g. operations sequence, time study, layout interpretation, etc.). Preferentially the information collected from the technicians and operators should be done at the shop-floor and without the presence of the responsible (a formal meeting inhibits the natural development of empathy between students and employees). This task of the diagnosis phase must be compact: it should run for about two to three weeks, with at least a four days-a-week presence of the students at the company to guarantee their natural permanence in the manufacturing system environment. The success of this task depends on the quality of the information gathered. So, students should transmit to the company employees the interest of the project for all of them, demonstrating a high level of motivation on running the different tasks. The professor must control remotely this task, checking the relevance, the quality and quantity of the information collected. Being aware of the student's academy requirements (exams, classroom attendance, laboratory work, etc.), the professor must coordinate the beginning of this task in order to assure that it will be done without interruptions.

After collecting the information, the students can continue the diagnosis through the identification of weaknesses, strengths, limitations, critical points, etc. and through the purposing of general solutions – these two tasks should not be performed at company premises. The outputs of this phase are a short and concise report (readable by the company!) and, most important, an oral presentation of the first phase results in a working meeting. Top management as well as the accompanying responsible and technicians from the company and the professor must attend and actively participate in this meeting. The main idea is to get involved all the intervenient of the decision-making process. Using informal brainstorming methods the professor must assume the leadership of the meeting. Beside collateral outputs (increase communication within company hierarchy, promote people empowerment and continuous improvement) the main meeting output is the identification of the solutions, understanding as action lines, to be developed in the next phase.

The last phase (phase 2 in Figure 1) comprises the detailed development of the solutions selected in the previous phase. Each solution must be described in detail and its technical and economical impact estimated and analysed. So, in this phase are developed either procedures or tools (mechanical systems, software, etc.), which must be validated with the available data. Usually, there is a need for the students to spend some more time in the company collecting new information or more precise data. Depending on the solutions complexity these tasks can long about four to six weeks. Nevertheless, generally, there is no formal need for regular visits to the company by

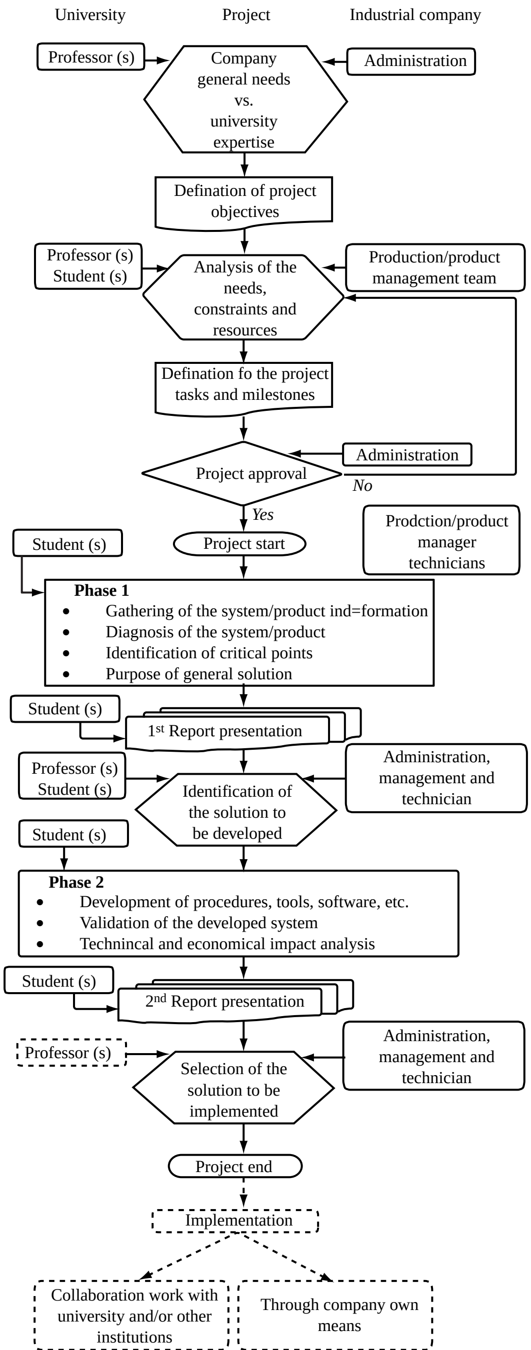

Figure 1.
Model schematisation

the students. As in the former phase, the professor must remotely control the students' work and the validation criteria used.

The presentation of the results of the solutions development phase is done using a procedure similar to the one used in phase 1: written report and oral presentation for a wide company audience. The impact of the developed proposals must be presented under more than one scenario to allow the estimation of the potential implementation benefits for the company in a simple but clear way. The aim is to provide the company with systematised, simple and technically and/or scientifically supported information to support the robustness of the decision-making process. Afterwards, company will select some of the proposed solutions for future implementation, requesting the professor opinion (or not). After the project the implementation phase can be performed either through company own means or through a collaborative work with the university and/or other institutions.

Case studies

This section presents several success case studies, where the described model and collaborative work procedure were used. It is important to remark once again that before the development of this model some unsuccessful cases occurred. The unsuccessful was mainly related with the students psychological profile not assertive enough to face challenges and overcome difficulties without loose a high motivation level, with the inadequate expectations management carried out by the professor and, finally, with the reduced commitment of company top management and collaborators in the support of the project.

SMED case studies

Two projects based on the SMED[1] method were conducted at two individual companies. The main aim was to increase the shop-floor productivity and flexibility. The companies are very similar. Their main business is to supply automotive assembly lines with sheet-metal forming parts.

Company A has about 350 employees and produces about 10,000 ton of parts per year. Among other equipments this company has a total of 35 presses (mechanical and hydraulic), with a nominal capacity between 20 and 800 ton. The project specific aims were the development of a standardized procedure to simplify the tools design process and also to reduce the presses setup time in 25 per cent without any investment requirement (constraint imposed by the company). Two students in direct and close relationship with the head of manufacturing sector of the company carried out the project during ten months. It was developed an application tool (based on Microsoft Excel) comprising, for all the press tools, geometrical and technological information and standard best practices for the support of tool design process. The usefulness of this software was high in what concerns the systematizing of design solutions and it began to be used by the company immediately after its presentation and before the project end.

For the SMED part of the project 19 presses were selected, particularly the ones with a worst performance level and with a major productivity impact in the tool exchange operation. Owing to similarities of some of the presses and/or of the setup characteristics the 19 equipments were divided in three groups: smaller presses (automatic feeding) with an average setup time of 57 minutes; larger presses (automatic feeding) with an average setup time of 75 minutes; and manual feeding larger presses with setup time around 30 minutes. At phase 1 the students conducted time measurements as well as detailed identification of all operations performed during the setup. A new setup procedure was developed at phase 2, for each press group, reducing and/or eliminating internal operations and transforming some of the former internal operation into external ones. The only costs involved were related with the personnel training on the new procedures. As seen in Figure 2 the results of the project were beyond the objectives, with setup time reductions between 50 and 60 per cent. Six months after the end of project the company implemented these procedures and extended them to the other presses.

Company B, although smaller, is similar to company A, working in the same industrial sector and using the same core technologies. It has 140 employees and produces around 7,500 ton of parts per year. Among other equipments this company has a total of 45 presses (mechanical and hydraulic), with a nominal capacity between 10 and 800 ton. Also developed by two students during 12 months, this project aim was to reduce setup to 50 per cent of the present time. From the preliminary observations three groups of presses were identified: low capacity with automatic feeding, high capacity with automatic feeding and low capacity with manual feeding. For a deep analysis the four presses with more setup problems in each group were selected.

At the diagnosis phase, similar to the one performed in company A, the students estimated setup time reductions under three scenarios for each press group. Scenario 1 only involves new work methods for the setup (modification of the operations and resources organization); scenario 2 includes scenario 1 and requires the development and/or acquisition of special systems to reduce internal operation time; including previous scenarios, scenario 3 aims to reduce external operation through transportation systems improvement, mainly between the tools warehouse and the presses shop-floor.

The reduction in setup times achieved (between 68 and 86 per cent) was higher than the one stated in the project objectives (Figure 3). For the phase of development the company requested the students to develop the detailed setup procedure for all of the press groups and also to perform a technical and economical analysis of the solutions purposed under scenario 2 for the presses of the group 1. Company's top management decided to start the operators training on new setup procedures during the second report presentation.

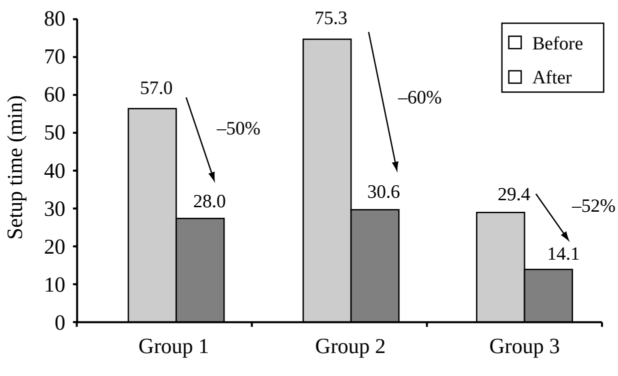

Figure 2.
Setup time reduction in the three press groups for company A

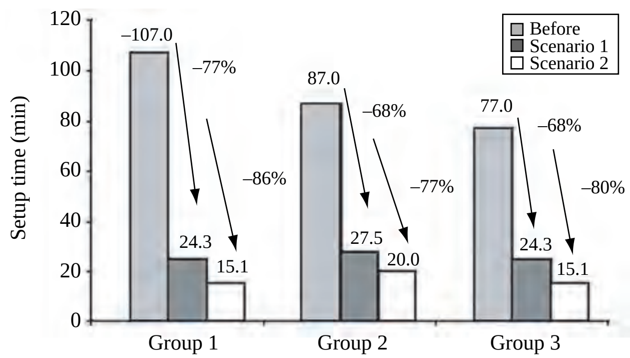

Figure 3.
Setup time reduction in the three press groups for company B

Lean assembly line case study

Company C among other activities like metalworking and industrial parts painting, runs a production line in which medium and light-duty trucks are assembled, under a components knock down approach. The truck's parts are produced by a Japanese manufacturer and arrive at company C as a "puzzle" to be assembled. The line is composed by eight workstations where 16 operators perform assembly operations like screwing, fixing, riveting and other essentially manual actions. The daily production capacity before the project were launch was between four and six trucks per shift, depending on the truck model.

The objective of this project was to increase the assembly-line productivity, in particular to increase the line output without any increase in the resources, through the implementation of lean manufacturing strategies. Since the company needed a rapid answer to the problem, the work was performed during three months with the total dedication of two students. At the diagnosis phase three main topics were analysed: the layout, the materials flow for line-feed and the operation distribution and sequence at each workstation. Using direct observation, work methods and time study (stop-watch and work sample methods), the students identified critical operations, operation best sequencing and best distribution within workstations. Through the application of some lean manufacturing tools (5S, error-proofing, etc.) several simple and ready-to-implement solutions were purposed (parts quantity-fitted containers, coloured marks, one tool set per operator, etc.). With the information gathered about factory plant dimensions and constraints and also about the materials transportation volume between workstations, three alternative layouts were proposed.

After the first report presentation the company decided to implement the described simple solutions and to proceed with the operations re-sequencing by their own means. Therefore, the development phase involved the deep study of the impact of the three layout alternatives in terms of total production time and cost. Applying a cell-based philosophy to the workstation where the materials are pre-assembly and prepared to feed the line and quantitative methods to analyse the workers and parts movements, the three layouts were compared. Without giving deliberately one solution, the comparison between the three was based on three strategic scenarios: investment-, quality- and flexibility-based.

Owing to several constraints that did not exist at the time of the project, company C implemented another layout, actually a mixed of the three presented. The overall productivity of the assembly line increased about 45 per cent with a new production rate not below eight trucks per shift.

Simulation case study

This project used software-based discrete event simulation in order to assess the production system behaviour and the influence of some production parameters on its productivity. Two students performed it during ten months in the spot welding section of company A. This area receives the production orders on a daily base from the production control manager (the orders are pulled by the clients since the company works on a JIT[2] basis). Since there is a need to specific machine setup to each part assembly (there are 120 different parts), an economic production batch, always higher than the client order, is imposed. The extra quantities go to the section warehouse and are considered WIP[6] assemblies (Plate 1). To perform the welded assemblies this section receives un-welded parts from the press sections. The un-welded parts come in batches sized by the presses economic production quantities. Therefore, at this section warehouse there is a considerable amount of WIP parts, either before or after the spot-welding operations.

The aim of the project was to define strategies to directly reduce the WIP in this section and, indirectly, reduce the requirements of space for WIP storage and the total production cycle time. The first task performed by the students was the information gathering in order to describe, qualify and quantify the materials workflow. Following they grouped the 120 different parts in 25 families allowing data to be processed in a more rational way. Since several probabilistic variables were involved (order sequence, order size, setup times for each machine and for each sequence, unexpected events in the shop-floor), it was decided to use simulation as a sensitivity analysis tool. The project key tasks were the information gathering from different sources, the algorithms development and the manufacturing system modelling. This model was introduced in a commercial software tool base on discrete event simulation and several analysis and "what-if? …" tests were done upon it (Figure 4).

The system behaviour was evaluated in the model in terms of the amount of WIP parts and total production cycle time. Several sensitivity tests were run varying the batches dimension, order sequence, order dimension and variability. Recommendations

Plate 1.
Parts container of WIP parts just before the spot-welding operations

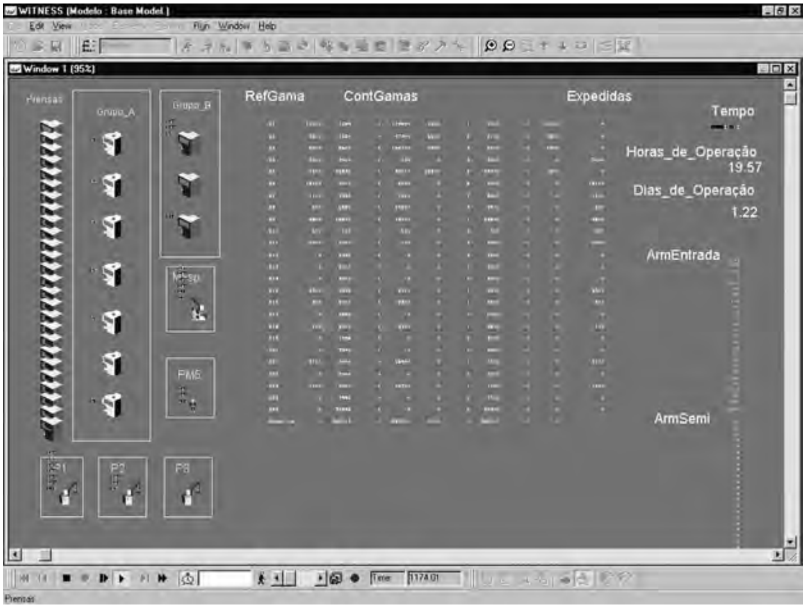

Figure 4.
Model interface image

were generated for each of the 25 assembly families. It was estimated that WIP of most of the parts/assemblies could be reduced to between 80 and 40 per cent of the present. A parallel result of the projects was a smooth introduction of a new analysis technique in the company. The contact with discrete event simulation tools allowed a clear evaluation of the benefits of such tools in an industrial environment where the productivity gains are mainly achieved through the improvement of the materials flow.

Conclusions

The experience carried on by a research university group in the promotion of the collaboration and teamwork attitude between the academia and SME companies, involving researchers, young engineering students and SME employees and top-management, was presented. The experience allowed the development of a collaboration procedure where several phases and milestones were defined and some best-practices were recommended. The collaboration towards a continuous improvement and innovation process is promoted following a bottom-up approach. The objective is to focus in localized and specific problematic areas in the industrial companies where the potential of improvement and innovation is large, to diagnose the situation and propose new and efficient solutions supported by technical/scientific methodologies. Small projects allow both collaborators, academia SME companies, to smoothly define their roles, achieve high levels of personal trust and design achievable expectations within their competencies, which are the basic foundations to successfully develop large and risky research projects.

The results achieved so far demonstrated a set of benefits:

- training of young engineering students for an active problem-solving attitude, within a systemic industrial perspective;

- smoothness of the students transition to their professional life; and
- promotion of a collaboration culture between SME and academia world for real problems-solving and for continuous improvement and innovation processes.

Notes

1. SMED – single minute exchange of die.
2. JIT – just-in-time.
3. TQM – total quality management.
4. TPM – total productive maintenance.
5. MRP – manufacturing resource planning.
6. WIP – work in process.

References

Alazmi, M. and Zairi, M. (2003), "Knowledge management critical success factors", *Total Quality Management & Business Excellence*, Vol. 12 No. 2, pp. 199-204.

Cahill, E. (2001), "Breaking the mould: European manufacturing in the knowledge economy", *Foresight*, Vol. 3 No. 4, pp. 297-308.

Conceição, P., Heitor, M.V. and Oliveira, P. (1999), *University-based Technology Licensing in the Knowledge Based Economy*, Techovation, Lisbon.

Davenport, S., Davies, J. and Grimes, C. (1999), "Collaborative research programmes: building trust from difference", *Technovation*, Vol. 19 No. 1, pp. 31-40.

Demain, A.L. (2001), "The relationship between universities and industry: the American university perspective", *Food Technology and Biotechnology*, Vol. 39 No. 3, pp. 157-60.

Graff, G., Heiman, A. and Ziberman, D. (2002), "University research and offices of technology transfer", *California Management Review*, Vol. 45 No. 1, pp. 88-115.

Guthrie, B. and Warda, J. (2002), "The road to global best: leadership, innovation and corporate culture", The Conference Board of Canada, Innovation Challenge May, Paper #1, pp. 1-8, available at: www.conferenceboard.ca/inn/expertise/mng_tech.htm

Harmon, B., Ardishvili, A., Cardozo, R., Elder, T., Leuthold, J., Parshall, J., Raghian, M. and Smith, D. (1997), "Mapping the university technology transfer process", *Journal of Business Venturing*, Vol. 12 No. 6, pp. 423-34.

Jones-Evans, D., Klofsten, M., Andersson, E. and Pandya, D. (1999), "Creating a bridge between university and industry in small European countries: the role of the industrial liaison office", *R&D Management*, Vol. 29 No. 1, pp. 47-56.

Keeble, D., Lawson, C., Moore, B. and Wilkinson, F. (1999), "Collective learning processes, networking and 'institutional thickness' in the Cambridge region", *Regional Studies*, Vol. 33 No. 4, pp. 319-32.

Klofsten, M. and Jones-Evans, D. (1996), "Stimulation of technology-based small firms – a case study of university-industry cooperation", *Technovation*, Vol. 16 No. 4, pp. 187-93.

Liyanage, S. and Mitchell, H. (1994), "Strategic management of interactions at the academic-industry interface", *Technovation*, Vol. 14 No. 10, pp. 641-55.

Lyu, J. and Gunasekaran, A. (1993), "Implementation of advanced manufacturing technology trough industry government university cooperation in Taiwan", *Computers in Industry*, Vol. 22 No. 2, pp. 187-91.

Mateus, A. (2000), *Diagnóstico Prospectivo de Indústria Metalúrgica e Metalomecânica Portuguesa*, Associação Nacional das Empresas Metalúrgicas e Metalomecânicas, Lisboa.

Matlay, H. and Hyland, T. (1999), "Small firms and the university for industry: an appraisal", *Educational Studies*, Vol. 25 No. 3, pp. 253-67.

Mesquita, R., Peças, P. and Gomes, S. (2000), "Situação e Tendências do Sector Metalomecânico", in Tavares, L.V. (Ed.), *A Engenharia e a Tecnologia ao Serviço do Desenvolvimento de Portugal*, Editorial Verbo, Lisboa, pp. 295-302.

Murphy, J. (1993), "A degree of waste – the economic-benefits of educational expansion", *Oxford Review of Education*, Vol. 19 No. 1, pp. 9-31.

National Research Council (NRC) (1998), *Visionary Manufacturing Challenges for 2020*, National Academy of Science, Washington, DC.

Santoro, M.D. and Chakrabarti, A.K. (2001), "Corporate strategy objectives for establishing relationships with university research centers", *IEE Transactions on Engineering Management*, Vol. 48 No. 2, pp. 157-63.

Sheather, G., Martin, R. and Harris, D. (1993), "Partners in excellence – a new model for cooperative education", *Educational & Training Technology International*, Vol. 30 No. 1, pp. 5-31.

Tavares, L.V. (2000), *A Engenharia e a Tecnologia ao Serviço do Desenvolvimento de Portugal*, Editorial Verbo, Lisbon.

Todd, R.H., Red, W.E., Magleby, S.P. and Coe, S. (2001), "Manufacturing: a strategic opportunity for engineering education", *Journal of Engineering Education*, Vol. 90 No. 3, pp. 397-405.

About the authors

P. Peças is a Research Assistant at Mechanical Department of Instituto Superior Técnico. Paulo Miguel Nogueira Peças received the Master's Thesis on Laser Welding of Taylor-Blanks (1998) and also a PhD student (Thesis theme: Technology transfer to mould industry). Several papers were published in international journals and international conferences. Paulo Miguel Nogueira Peças is the corresponding author and can be contacted at: ppecas@ist.utl.pt

E. Henriques is an Assistant Professor at Mechanical Department of Instituto Superior Técnico. The author completed the PhD thesis on Integrated Process and Production Planning (2000). The main areas of interest are agile and robust manufacturing systems and technology transfer to SMEs. Also, several papers were published in international journals and international conferences.