Integrated Design and Manufacturing Systems for an Engineer to Order SME

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Abstract. For the last thirty years, manufacturers have attempted to integrate their information systems. The benefits of doing this for a manufacturer are both obvious and significant. Despite this, however, case studies describing centrally designed and integrated manufacturing information systems have been largely restricted to larger organisations. While it is not unusual for Small and Medium Enterprises (SMEs) to link some of their sub-systems, it remains relatively rare for such businesses to attempt to design and implement a single, integrated information system from the top down. This paper reports on a systems development project undertaken by the Manchester based SME, S+B Ltd. The company initiated an ambitious Knowledge Transfer Partnership (KTP) project in 2016 with the goal of designing and implementing fully integrated systems that embraced Computer Aided Design (CAD), manufacturing technology and Enterprise Resource Planning (ERP). The projects objectives were three-fold; first to improve efficiency and eliminate duplication of effort. Second, to reduce the number of errors that are created by the ad-hoc transfer of data between sub-systems. Third and most important, to reduce the number of times information was transferred between sub-systems to shorten lead-times to customers. This paper reports on the various steps undertaken during the project from the initial process mapping exercise through to the implementation of the new systems.

Keywords. Parametric Design; Solid Modelling; CAE; CNC Machines, Enterprise Resource Planning (ERP).

1. Introduction

Since the 1980s, manufacturers have attempted to integrate their information sub-systems. The benefits of this process, often labelled as Computer Integrated Manufacture (CIM), can be significant [1]. It is now common to re-use the geometry created in a Computer Aided Design (CAD) system to drive Computer Numerically Controlled (CNC) machines. Similarly, automatically transferring Bills of Material (BOMs) from a CAD system into an Enterprise Resource Planning (ERP) package eliminates duplication of effort. There are numerous reports in the literature of the benefits achieved from such endeavours [2, 3]. Today, terminology has evolved and many of the ideas that underpinned CIM have been subsumed and expanded into the newer and broader concepts of Industry 4.0 and Smart Manufacturing (SM). While systems integration is now by no means novel, Small and Medium Enterprises (SMEs) have lagged behind larger organisations in the application of such ideas. As far back as the late 1990s, several studies reported on the challenges faced by SMEs in introducing advanced technologies such as CIM, while acknowledging the potential benefits [4-8]. These challenges and potential benefits are still relevant today [9-11].

In 2016, S+B UK Ltd. embarked on a two-year project to improve its systems. To support this work, it initiated a Knowledge Transfer Partnership (KTP) with Manchester Metropolitan University (MMU). At the time of writing, this project is roughly 75% complete. S+B is a relatively small, independent company based in Manchester UK with around fifty employees and an annual turnover of around £8M. The company is leading supplier of laboratory furniture. Customers fall into two categories; education and industrial. When initially introduced to S+B, the academic members of the KTP team were impressed by the vision of the company's management to produce exciting laboratory working environments for young people to motivate them to engage with science. Traditional laboratory furniture designs have been rather dull, and this is in contrast to the products manufactured by S+B (see figure 1.).

Figure 1. Example of an S+B Produced Chemistry Laboratory Workspace for a School.

2. Project Approach

2.1. Initial Analysis

The first task was to systematically investigate and map S+B's manufacturing and information systems. Given that the overall aim was to improve the company's operations as a whole, the initial investigation was far-reaching and considered all processes from initial quotation through to installation of laboratory furniture on-site. The mapping approach chosen was $IDEF_0$ as this allowed the complexity of the business to be captured. Once the existing systems had been mapped, a new, optimised plan was developed. These $IDEF_0$ models were highly detailed and complex, but the top-levels are shown in figure 2. In addition to the mapping work, a systematic Pareto analysis of operational problems was undertaken. A key project objective was to reduce the lead-time from receipt of a customer invitation to tender to physical installation. Thus, in the optimised plan, the number of discrete steps in the end to end process would be reduced. By doing this, work would have fewer opportunities to queue, thus reducing the overall lead-time. Secondary project objectives were to improve efficiency and reduce errors in design, manufacture and installation. At the outset, it was felt that S+B's systems could be considered as part of a network made up of several sub-systems; CAD, generation of CNC part-programmes, ERP and the manufacturing technology itself. Initially, the team considered all of these as being equally important. Following the work described above, however, it became clear this was incorrect; in fact, it was design that was pivotal. With hindsight, this is not surprising; S+B's core competence is innovation in design and the ability to tailor designs to meet customer requirements. The manufacturing processes themselves are not innovative; the challenge is to transfer detailed customer requirements into the factory in an efficient and error-free manner. It was for this reason that the initial project focus was on CAD and it was decided that a new package was essential to support the project objectives.

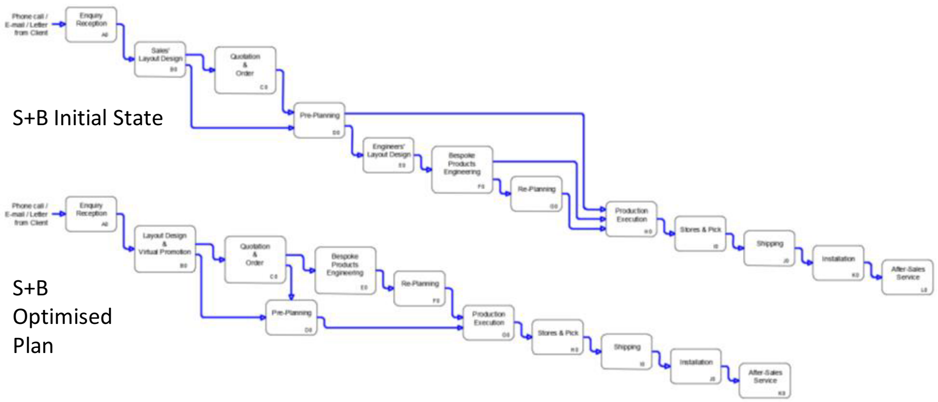

Figure 2. Simplified Process Maps for S+B – Initial and Optimised States.

2.2. Parametric Design and Solid Modelling

Engineering drawings have been used as a means of conveying information between designer and manufacturing. In the 1960s, 2D modelling techniques were developed to represent objects mathematically in a computer. 2D models simply consist of points, lines, arcs, etc, but by the early 1970s, a 3D wireframe could be subjected to 3D translation and rotation, giving a greater illusion of solidity. This relieved users of some of the interpretive burdens; but automatic volumetric analysis was limited or non-existent. In addition, such systems cannot guarantee the validity of the defined geometry and are subject to ambiguous interpretation [12]. A surface representation of an object is less ambiguous and more complete than a wireframe model. The development of early solid modelling systems enabled a wide range of applications to be automated, such as the computing of mass, volume, and moment of inertia. The early solid modelling systems were incapable of supporting manufacturing requirements such as tolerances and process planning. Later, attempts were made to represent tolerances in solid modelling systems [13]. Modern solid modellers, such as Pro/Engineer, have feature based design which enables users to define products in terms of features such as holes, slots, etc. Another relevant feature of CAD systems is design parameterisation. This functionally allows engineers to define design variables that determine the final geometry of entities. Such systems are built around rules that maintain the viability of a design when a relevant parameter is changed [14]. Given that lab furniture needs to fit within a room, there are obvious parameters that are important in determining the nature of a design (e.g., the length or height of a lab bench).

2.3. Package Selection

The project team drew-up detailed requirements for the new CAD package. Key to these requirements was design parameterisation. It was crucial to the project to be able to configure standard products to meet the requirements of customers without the need to design everything from first principles. It was recognised that there would always be occasions been it would be necessary to produce completely bespoke designs. In most cases, however, it was believed parametric design would be both possible and valuable.

A shortlist of packages was drawn-up and vendor demonstrations were organised. Using a scoring system, shortlisted systems were compared to the pre-defined requirements. The IMOS package scored highest and thus was subjected to further scrutiny. This involved more extensive software demonstrations, a visit to the IMOS headquarters in Germany and tours of manufacturing sites who had implemented the package. Based on the work carried out, it was decided to purchase IMOS in late 2018. A strong feature of IMOS was that it was optimised for furniture design.

2.4. Implementation Work

The implementation work has essentially two components:

- **Configuration of the IMOS package for design parameterisation.** A substantial amount of effort was required by the team to set-up IMOS so that customer designs could be created parametrically.
- **Linking the IMOS package to the other S+B sub-systems.** This component was essential to meet the project aims for increased efficiency and reduced errors. This meant that the processes for transferring data between IMOS and the other S+B sub-systems needed to be robust. This required a considerable amount of effort on the part of the team, but also significant input from the sub-system vendors. A conceptual map of S+B's planned information systems is presented in figure 2.

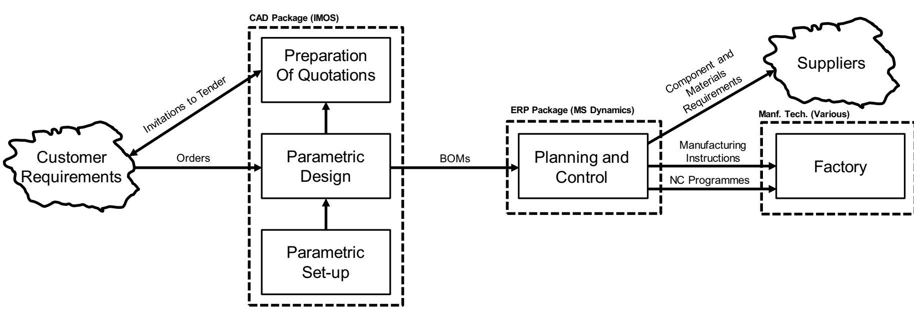

Figure 3. The New Information Systems of S+B.

At a technical level, the new system works well. There is, however, a challenge in terms of the design staff. The fundamental nature of people's work has changed and thus the team is investing significant amounts of time in training on the new systems.

The integration of the IMOS software with the ERP package (Microsoft Dynamics) and S+B's CNC machines is more of a technical challenge than a human one. There have been some teething troubles as might be expected, but successful trials have taken place. BOMs have been successful transferred from IMOS to Microsoft Dynamics. NC part programmes have been successfully generated automatically for S+B's routers and band saws. Direct Numerical Control (DNC) has been achieved without the need for any physical wiring; fortuitously, S+B's existing ethernet network was exploited to enable the data transfer. Laboratory worktops have now been machined on the shop floor with minimal human intervention. It is expected this approach will replace manual on-machine part-programming entirely in the future.

3. Results and Discussions

At the time of writing, the IMOS system has been fully configured to allow parametric design to commence. It is now possible to design an entire lab parametrically by dragging and dropping standard units onto a floor plan. IMOS is sufficiently sophisticated to allow automatic re-sizing, based on the rules that were pre-defined by the team, without the need to engage in detailed design calculations. The software has solid modelling capability, so interference between specified collision sensitive areas can be detected automatically. In practice, some lab elements cannot be designed purely parametrically. This means that there is a still a need for some new product development work. Such work in IMOS can only be considering as being semi-automated (though still requiring much less effort than using a non-parametric 2D CAD package). Overall, the design effort for the typical mix of work in S+B has been greatly reduced. A test conducted by the team showed that a lab design (see figure 4) that once required seven-hours of work can now be completed in 40 minutes. A rendered representation of the finished room is shown in figure 5. The rendering took only 40 seconds on a standard Windows 10 desktop computer that cost only £1,500.

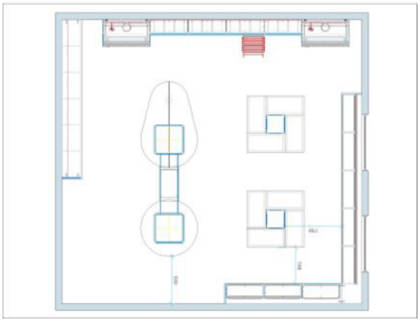

Figure 4. A Lab Design Configured Using IMOS.

Figure 5. IMOS Rendered Image for the Lab Configuration Shown in Figure 4.

4. Conclusions

The project team is confident that the implementation will be complete before the end of the KTP project in September 2019. When the implementation is complete, information systems in S+B will be fully integrated from end to end. While no metrics have been collected as yet, it is evident that lead-times will be substantially reduced. Furthermore, there is good reason to believe that less effort will be required in the mechanics of the design process. This will create more time for value-adding activities such as working with customers or developing new offerings. The company is confident the very substantial investment it has made will be justified. Returning to the arguments presented at the start of this paper, integration has yielded substantial benefits. It is interesting to note, however, that this has been achieved in a business with a turnover of £8M. One of the things that has made the project possible, is that it has been done in the context of a KTP. In the literature cited at the beginning of this paper, one of the main reported problems in achieving systems integration in SMEs was finding enough time to carry out the required work. The availability of KTP associate to work full time on this project has proved a key factor for success here.

Acknowledgments

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