Use Cases and Concepts for 3D Visualisation in Manufacturing

Bernhard Wolf, Gerald Mofor, Jochen Rode

SAP AG
SAP Research CEC Dresden
Chemnitzer Straße 48
01187 Dresden
{b.wolf, gerald.mofor, jochen.rode}@sap.com

Abstract: We propose and analyse six use cases for 3D visualisation in manufacturing attempting to identify business scenarios for which 3D visualisation can add value in supporting manufacturing operations. This early qualitative work is based on a theoretical analysis of potential use cases. In addition to the analysis, we discuss the required data and data sources, and finally propose a number of basic concepts for visualising different kinds of manufacturing data.

Keywords: 3D visualisation, simulation, use cases, manufacturing, user interface

1 Introduction

Within the domain of manufacturing, 3D visualisation and simulation tools are currently mostly used to support product and plant layout design as well to facilitate the sales process for machine manufacturers (see [Vi07, Ugs07, De07] for example). While these use cases are valuable we believe that 3D visualisation can be beneficial for other purposes as well. In particular, it may also be used to support day-to-day manufacturing operations be it to facilitate communication, training, problem solving, or operations monitoring (e.g. 3D-SCADA systems like PcVue [Pc07]). Section 2 of this paper analyses six use cases attempting to identify business scenarios and processes where 3D visualisation can add value in supporting manufacturing operations. Section 3 discusses the data required for visualising aspects of the manufacturing process as well as the sources of these data. Section 4 proposes basic concepts for visualising different kinds of data. Finally, section 5 concludes with an outlook on the possible future of 3D visualisation and simulation within manufacturing.

2 Use Cases

This section discusses six potential use cases for 3D visualisation. We do not aim to provide a broad set of use cases [McL01] but rather focus on those that appear to deliver the most value for supporting manufacturing operations. This early work is based on a theoretical analysis and our experience with 3D visualisation tools. We plan to validate it through prototypes and user testing in the near future.

As a result of the plant layout design process many manufacturers already posses a 3D model of their plant. However, currently few companies repurpose this model. If the full potential of 3D visualisation and simulation should be exploited, these existing models can significantly lower the entry barriers and costs [McL01] for other usage contexts. The existence of a 3D model is therefore an important criterion for evaluating the cost-benefit balance for each of the use cases discussed in the following.

2.1 Communication and Demonstration

Within every manufacturing company there is the need to communicate and illustrate thoughts and ideas. For example, the foreman may want to explain a particular problem from the previous shift to the production supervisor or the production supervisor may want to share some ideas for process redesign with his engineering crew. Sometimes the course of such discussions may turn out to be very technical, especially when a staff member needs to clarify a point. Participants with a non-technical background or those that are not deeply involved in the process under discussion (e.g. the CEO) may have difficulties following a debate.

The intuitive nature of 3D visualisation can be exploited to serve as a platform for illustrating and communicating ideas between the staff members. A 3D visualisation can be very close to the reality and therefore help users to quickly recognise the point of interest. The ability to overlay different types of information (e.g. process master data like plant layout or routings, transactional data like production orders, real-time data like production progress or machine status) from different sources such as real-time databases, Manufacturing Execution Systems (MES), or Enterprise Resource Planning (ERP) systems can help to explain processes, show interdependencies, and highlight problems.

2.2 Plant and Process Engineering

In the quickly changing environment of today's business, new manufacturing processes are frequently designed or existing processes re-designed. While powerful tools exist to facilitate plant layout design, comparable support is lacking for the design of routings (the sequence of operations and their allocations to resources for manufacturing a product). Ideally, a process engineer can explore different alternatives in a virtual environment before having to apply them to reality.

A 3D visualisation environment may give the process designer the sensation of being in direct contact with the factory shop floor. Through direct manipulation [Shn83] techniques he would be enabled to define and optimise routings in a visual way. Input and output materials could be visualised according to where they are needed or produced. This form of process design is likely to assist comprehension, increase efficiency, and help in preventing errors. If the visualisation is coupled with a simulation the redesign of the plant layout and processes can be supported in a similar way. With the help of what-if-scenarios, design flaws can be identified and eliminated in advance to physically changing the real world. This facilitates fast prototyping and reduces the likelihood for expensive re-designs.

2.3 Training

In order to address ever-changing customer requirements for increasingly individualised and complex products, manufactures need an educated and adaptive work force. Training, geared at improving existing skills or establishing new ones, is a frequent and important scenario for manufacturers. When a new employee joins a company, he needs to quickly get acquainted with the facilities and processes. He needs to learn about his future working environment (e.g. which machines he will operate or service), the production process (e.g. material routings), and so on.

While guided tours through the factory are ideal in many situations, they are costly (if needed to be repeated on a frequent basis) and often leave out important details, like inter-dependencies that are invisible to the untrained eye. Video shootings have been used in the past to address some aspects of this problem [Sa96]. However, creating videos is a costly process, they can quickly become obsolete when things change, and are not interactive, only showing one particular perspective.

3D visualisation can provide benefits similar to those of a guided tour or video while reducing the problems. Through a 3D visualisation it is easy to convey the “big picture”, it is easily updated when changes occur in the real world, and users can view the factory from all perspectives (using zoom, pan, and rotate). Since 3D visualisation supports different levels of abstraction it can also be used to train employees for the operation of a particular machine. To a large extent, employees can train themselves rather than requiring a mentor. Furthermore, they can do so, at any point in time perhaps when there is a no work for an extended period of time or if no mentor is available.

2.4 Localisation

Finding “things” like particular resources, tools, material, or WIP (Work in Process) or locating personnel is nowadays a frequent and time-consuming problem as manufacturing facilities grow more and more complex. For example, if a maintenance engineer receives an alarm notification which urgently requires his attention he must quickly locate the hot spot. This may be non-trivial in a complex plant or if the engineer is from an external service provider who is not familiar with the plant layout. A production supervisor may want to find a particular order to be able to report the status back to an important customer.

Compared to textual directions, a 3D visualisation is closer to the mental image of the person trying to locate a particular item, be it a machine, WIP, or something else. This is likely to speed up the finding process. The visualisation may be provided through regular desktop user interface or even using mobile technology. Visual support may also be helpful for finding plant personnel. If the visualisation and location system were integrated with a “skills database”, in an emergency a dispatcher may even be able to ask for the location of all maintenance engineers who are qualified to repair a particular machine. While 3D visualisation promises to solve the localisation problem it depends on the availability of location data. This typically requires a highly integrated system for manufacturing data acquisition. If plant personnel are supposed to be locatable as well, privacy and security concerns may be particularly challenging.

2.5 Monitoring and Control

Close monitoring of the production process is necessary in order to detect deviations from the plan early on. Production supervisors monitor the production progress and look out for exceptional situations.

3D visualisation can serve as a monitoring tool. Changing the colour of machines depending on their current status, visualising the material flow, or showing real-time data about the progress of a particular order would improve the overall visibility. Exceptions could be shown at the point where they occur. From an alarm message, a hyperlink may lead the user directly to a visualisation of the problem.

The 3D model may not only serve to monitor production but also to control it. The production supervisor may visually dispatch or reroute orders or request the maintenance of a machine simply by choosing the appropriate action in the “context menu” of a particular object.

2.6 Maintenance and Repair

Maintenance and repair are essential tasks for every manufacturer. As most manufacturers use a large heterogeneity of equipment with differing maintenance cycles, the knowledge of how to maintain and repair a particular machine is not always readily available. Appropriate manuals have to be found and carried to the location of the resource requiring repair or maintenance.

3D visualisation can assist the maintenance engineer not only by helping to locate the target resource but also visualise detailed instructions for completing his tasks (e.g. open cover xyz, unscrew here, replace part…). In most cases, this visualisation would need to be available at the place where the work is performed. Therefore, a mobile solution (e.g. laptop, PDA) would be necessary, creating additional requirements for network connectivity and/or data synchronisation with the central system of record.

3 Data Requirements for Visualisation

In order to implement 3D visualisation support for the previously discussed use cases, information from different data sources is required. The basis for the visualisation is one (or more) 3D model(s) of the plant layout. These models are often readily available as the result from the plant layout design.

However, apart from the 3D geometric data other data is required and needs to be mapped to the visualisation. These data can be classified in four categories, namely: master data (i.e. data valid for an extended period of time), transactional data (i.e. data relevant for a shorter time frame and a particular business transaction), real-time data (i.e. current data from the manufacturing process), and KPI data (i.e. key performance indicators that aggregate other data).

For each of these categories, current as well as historical data may be relevant. For example, if the production supervisor wanted to explain a problem to the plant manager he may need to "take a look into the past" perhaps requiring access to data about production orders long finished. Figure 1 shows that data from systems on different levels of the "automation pyramid" (ERP, MES, low-level process control systems on the shop floor) are integrated for generating the 3D visualisation used by the plant personnel.

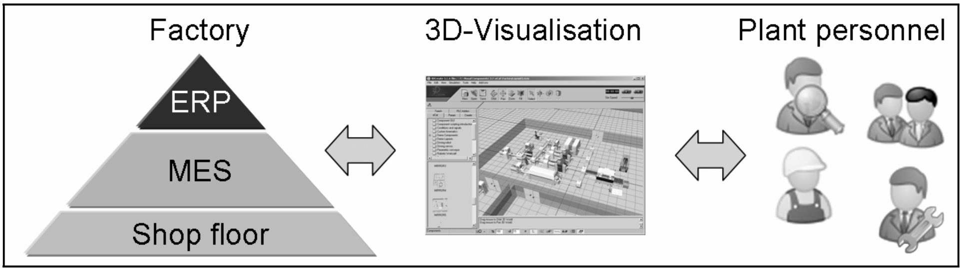

Figure 1: Data from different sources is integrated to generate a 3D visualisation used by the plant personnel

Master data relevant for implementing the discussed scenarios include the plant layout (locations, resources), the plant personnel (skills), the process (routings), the bill of material (BOM) structure, tools, and maintenance documents. The systems of record for these types of master data are typically ERP systems and MES.

Transactional data include production or maintenance orders and confirmations. Transactional data are typically managed in MES and ERP systems.

Real-time data include process and resource information like machine status (e.g. available, idle, working, tool break, in repair…), current yield, scrap, and rework quantity, operating hours, process parameters (e.g. tank fill level or temperature), exceptions (e.g. unplanned downtimes, breakdowns), and WIP locations. Real-time data originate either from the shop floor (machine data) or from the MES (information derived from technical data).

KPI data provide meaningful feedback about the performance of a production process and include such KPIs as OEE (e.g. Overall Equipment Effectiveness), quality data etc. KPI data is typically generated and processed by the MES.

4 Concepts for Visualisation

In the previous section, the data requirements for 3D visualisation were established. This section discusses possible approaches for visualising different types of data. For illustration purposes, four types of visualisation have been chosen. These four types do not map one-to-one to the previously discussed use cases but are rather components that could be used for different purposes. Figure 2 shows an example for each of the four scenarios.

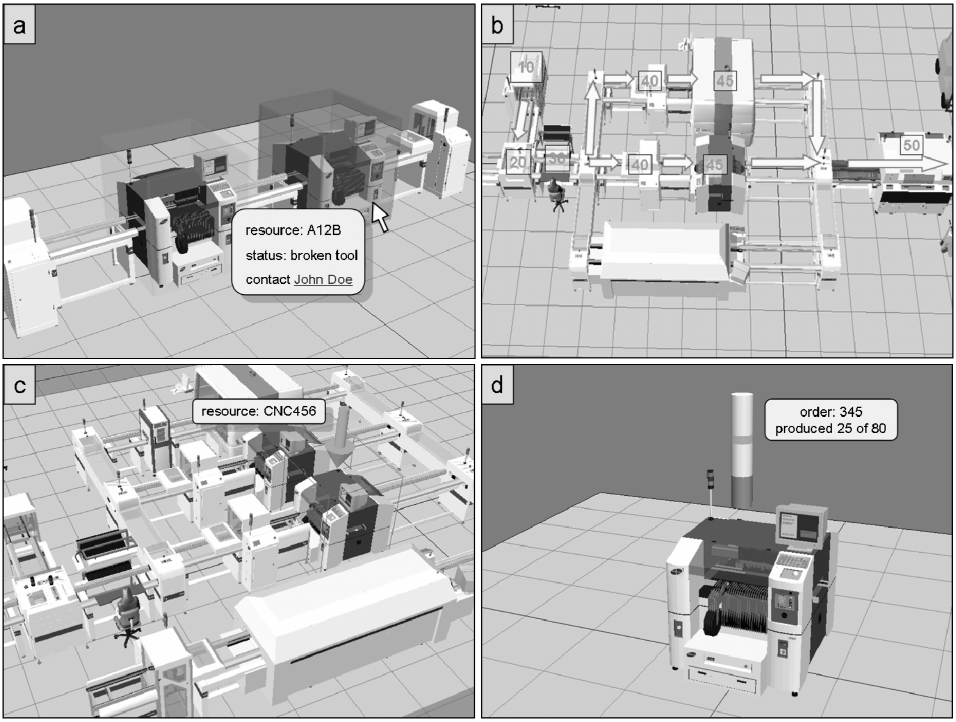

Figure 2: 3D visualisation scenarios

4.1 Resource Status Visualisation

Figure 2a) shows machines in a production line. These machines are modelled in the ERP/MES as resource entities. The status of the resource is illustrated by surrounding the machine with an appropriate colour. The colour scheme is based on the European norm on safety of machinery IEC 60204-1 [IEC1]. For example a green colour signifies that the machine is working properly. Red, on the other hand, signifies a malfunction. The colours are semi-transparent in order not to obscure the visibility of the machine. Additional resource information (i.e. resource id, detailed operational status, contact person) is visualised in a tool tip which appears at mouse over. As this is merely an example, the content of the tool tip might contain different information and may be user-role dependent.

Furthermore personalisation might allow adapting the view by enabling or disabling irrelevant information (e.g. the green wrapping may not be necessary). A context-sensitive menu may provide actions such as "schedule maintenance" or "contact responsible engineer" (not shown in Figure 2a). The visualisation could be made more accessible for colour-blind persons by using a redundant encoding scheme (e.g. using colours *and* icons to indicate the status).

4.2 Routing Visualisation

Figure 2b) illustrates how routing information is overlaid on the plant layout showing the path that the WIP will take while being processed. Several different routings can exist to produce a particular product. Also, within a routing, alternative paths are possible. In the example, operations 40 and 45 can be executed on alternatives resources. The numbers represent the operation sequence order. Additionally, information about input and output materials may be overlaid at the points they flow into or out of the process (not shown in the figure). As a visualisation of a production process can be very complex, it should be possible to enable and disable different information layers.

4.3 Localisation Visualisation

Figure 2c) illustrates how objects that are being searched for can be highlighted. The system may offer to locate the position of objects by name or ID (e.g. machine, production order). The result of the search is one (or more) arrows, directly over the found object(s). There may be additional information displayed about the found object. In the example, simply the resource ID is displayed.

Finding a path to an object could also be equally important in a large facility and may be realised by indicating the way with arrows on the shop floor inside 3D visualisation (see [Fi05] for example).

4.4 Production Progress Visualisation

Figure 2d) illustrates how the progress of a particular production order may be visualised. In the example, a cylindrical progress bar is placed on top of the resource and shows information about the processed order. The motivation for using a cylinder is to ensure a uniform view of the progress bar from all horizontal perspectives. Alternatively, the overlaid information may always auto-rotate to be perpendicular to the viewpoint of the user (as shown by the tool tip). The green colour in the bottom part of the progress bar represents the quantity of material the machine has produced so far, the length of the bar the planned quantity, while the white stands for the quantity that still has to be produced. To show whether production is on schedule, an orange deviation marker is used. The marker is a projection of the "expected quantity" that should have been produced until this moment in time. Ideally, the green bar would always extend until or beyond the orange marker. In figure 2d) the orange marker lies above the green boundary indicating that the production is behind schedule.

5 Conclusion and Outlook

In manufacturing, 3D visualisation has not been used to its full potential. We have discussed six use cases where 3D visualisation may facilitate production operations. As our analysis is a purely theoretical one, future work will need to validate the practicality of the use cases and the concepts for visualisation. While 3D visualisation holds a lot of promises it is not always a cost-effective or ideal solution. For example, for localisation, 2D visualisations in the form of maps provide similar value at a lower cost. Also, while certain use cases are frequently discussed as a potential uses for 3D they may not be appropriate for the task at hand. For example, while production scheduling is often referenced as an interesting use case, traditional tools like Gantt charts may be better suited than any 3D visualisation. On the other hand, 3D visualisation and simulation could become pervasive and an integral part of manufacturing operations, allowing the user to monitor the present, review the past, or look into the future by merely moving a time slider. In order to reach our vision of ubiquitous use and seamless user experience, different stakeholders like ERP, MES, SCADA, and CAD need to converge, data exchange standards agreed upon, and the cost of implementation reduced.

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