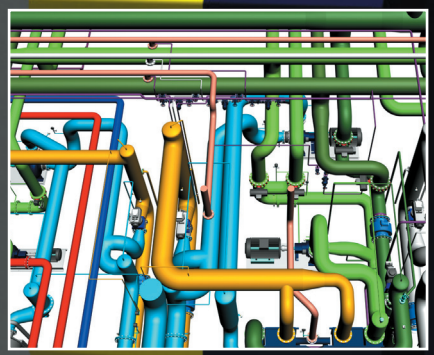
Special Edition 2004

Engineering Reuse, Modularization and Standardization in Plant and System Engineering



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The Best Way to Engineering Reuse

The reuse of engineering knowledge for the plant making and system business has tremendous benefits for the user. The powerful method of engineering reuse will be presented, including the necessary prerequisites. A few recommendations for implementation are included at the end of the article.

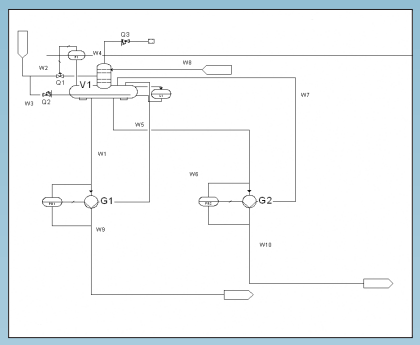


Figure 1: *Process Flow Diagram G2–v1: variant 2 pressures with 2*100%, 2*100%. Note for the tagging: the examples were tagged according to DIN 6779-13.*

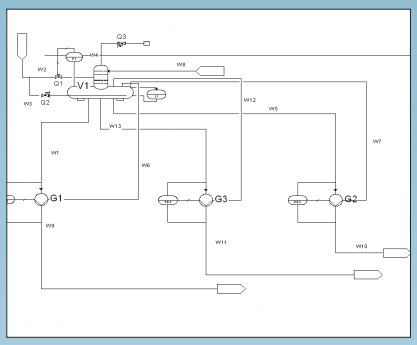


Figure 2: *Process Flow Diagram G2–v2: variant 3 pressures with 4*33%, 2*100%, 4*33%.*

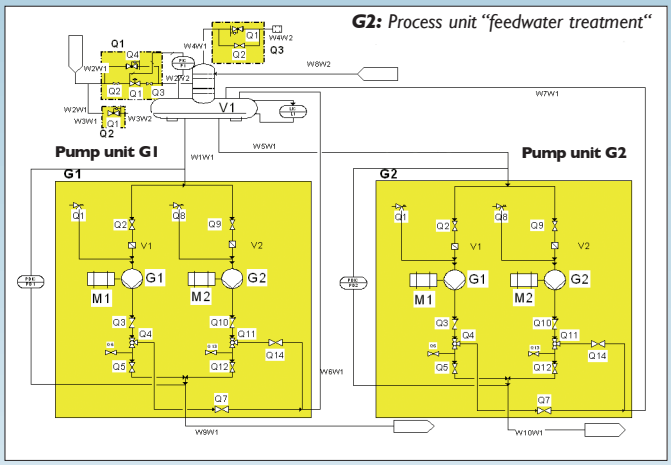


Figure 3: *Piping & Instrumentation Diagram Process unit "feedwater treatment": G2-v1*

Engineering, Procurement and Construction companies (EPC) and system integrators have been forced to become more and more competitive. They have been able to achieve this through new products (plants) showing improved plant economics. Well known examples are improved power plant efficiency or improved process plant yield, with even lower specific investment cost. Furthermore, the modularization of plants through module standardization has also been used to reduce investment cost. The benefits include a reduction of throughput time for engineering as well as of throughput time and cost for production, procurement and erection of the standardized modules. Firms could achieve different levels of success, depending on their focus to particular standards, their business models and the price policies applied to their customers.

Industry has always tried to use previously built solutions for its engineering activities. Therefore, the process engineer studies the requirements of the customer with the goal to conduct a process simulation based on his last Process Flow Diagram (PFD) or on the basis of a findable and best suitable modified PFD. The plant layout designer follows the same procedure for plant layout drawings. However, he not only has to consider whether an object (e.g., a vessel) exists in the PFD, but also whether its parameters are correct. The selection of the best template for the plant layout is certainly a very difficult task. It is therefore no surprise that plant layouts are generally started from scratch.

The data models of existing IT applications, such as simulators, 2D-CAD- or 3D-CAD-programs, are very functionally oriented and still developed based on efficient conduct of each specific functional engineering task. Such applications provide no cost information for the optimization of the technical solution. Therefore, use of the above described workflow will be very difficult for implementation of the necessary changes resulting from customer requirements, even with the existence of pre-engineered PFDs, P&IDs and 3D-models from modularization/standardization projects. Additionally, it will be very difficult to rapidly recognize whether reuse of a standardized module is feasable and to what extent it needs to be modified. The same applies to its connected modules. Experience has shown that a new methodology such as engineering reuse becomes necessary to allow standardized modules to be reused in the highly complex world of plants/systems. In the process engineering plant world, engineering reuse means, for example, the reuse of a PFD or its parts. Reusable objects include process units, PFD pages, equipment, control valves or connecting pipes.

Traditional IT applications for PFD creation are mainly used for optimization of the PFD drawing process. However, they seldomly provide a useful structure for reuse. Therefore, the structural levels in the PFD must be considered; these are required to allow reuse of the parts of the PFD from one project to another. One possibility is to select the level process unit. The decision must be made whether a process unit G2 (figure 1 above the feedwater treatment) shall be used for a new project to fulfill the requirements of the customer. Experience shows that there is often more than one solution (process unit variant) available to fulfill a certain function. The process unit variant is characterized by a certain number of objects (equipment, valves or similar) and the way they are connected with each other. Figures 1 and 2 show two different process unit variants. If we compare the engineering workflow for the creation of the process concept, the traditional approach would be the search for the necessary PFD pages from one or more already built or designed plants, and to correct them by hand. Within an environment which favors engineering reuse, the process variants are stored with additional descriptions in a Product Data Management system (PDM) for selection. This is illustrated in figure 1 with "G2—v1: Variant 2 pressures with 2X100%, 2x100%." The correct solution is found through answering questions such as: For what functional requirements has this variant already been chosen? What does it look like? What

are its key process parameters? How much does this variant cost? The assembly of the chosen process unit variants would then be done in a 2D-CAD application (PFD tool).

Selection of the correct structural level and its accompanying description is dependent on the chosen business model, the engineering discipline (process, instrumentation, electrical 3D design, etc) and the desired flexibility. For example, an additional level to the process unit could be introduced. In this case, a process unit would consist of several subfunctions which would have several variants (subfunction variants).

Another aspect is the relationship between the objects of the different engineering disciplines which are largely neglected in currently used IT applications. If those relationships are not stored in a database, it is impossible to go from the process concept (represented in the PFD), including its dimensioning and its ancillaries to main equipment (represented in the P&ID, see figure 3), to implementation of engineering reuse in 3D design.

The following description shows a possible workflow for the creation of the 3D model. Considering the process concept and the dimensioning of the equipment, it is possible to do a query based on certain criteria in the PDM, in order to visualize the already built main erection units with a difference of not more than one erection unit. The PDM system allows main erection units to be filtered, to list key parameters, e.g., the size class. It is certainly possible to compare at a higher level of detail, such as to find out which equipment unit is missing and which is superfluous. Visualization of the main erection unit is also possible. On the basis of this information, it is easier to make a decision on which main erection unit variant should be started for the delta engineering on the 3D model. A main erection unit variant is characterized by the objects which are included, their layout and their connection among each other. The size of the main erection unit is not part of the variant characterization. In the PDM, the objects of the main erection unit variant which are not needed are deleted or replaced by new objects which have been selected from the next level, such as the erection unit, equipment unit, valve unit or pipe section. In the example, the main erection unit variant "+B4—v1" has been chosen as the starting point. For the selection of the process unit variant, the variant "G2--v2" (figure 2) was chosen. Therefore, it is necessary to replace the erection unit variant "B4B1—v1" (figure 4) with erection unit variant "B4B1—v2" (figure 5) in the selected main erection unit variant"+B4—v1".

After the selection in the PDM, the 3D models will be automatically loaded in the 3D-CAD application for the delta-engineering. This includes all activities from the selected templates which comprise a complete and in itself consistent 3D model of the plant. A relationship must be established between the object (i.e., Pump G2G1) in the PFD (figure 1), the object (i.e., pump unit G2G1 in the P&ID (figure 3) and the 3D-CAD model, allowing the described workflow. The objects belonging to the pump unit must be marked as such during the buildup of the P&ID. The designer can then take this structure into account in the buildup of the 3D model and define the interfaces of the pump unit. Therefore, all objects such as shut-off valves, three-way valves, filters, non-return valves, piping sections and steelwork, which belong to the pump unit are defined. Similar to the main erection unit variant, the pump unit is characterized by the objects included, their layout and interconnection. As a result, a built variant from a project contains the full Bill of Material (BOM) and its associated cost. The BOM and the associated cost can be displayed with the pump object in the PFD through the existing relationship. And here it applies, too, that choosing the right structure levels and additional descriptions for the reuse depends on the business model, on the functions and on the desired flexibility and its handling. This also includes the "intelligence" of the 3D-CAD-application. It has already become evident that in the future this kind of application will allow more associative and rule based design work. This means that once an equipment unit variant, erection unit variant or main erection unit variant has been developed for a project of a certain size, the design of this variant can be adapted automatically when a different size is chosen. However, it might still take another couple of years before engineering reuse will work out on the above described level.

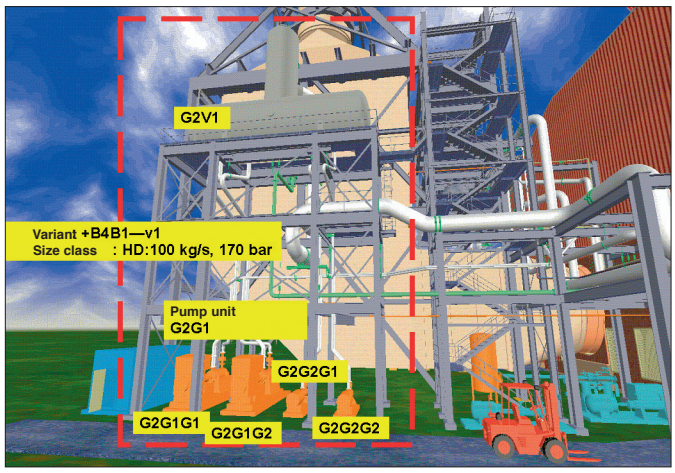


Figure 4: *Erection unit variant + B4B1– v1: Feedwater treatment*

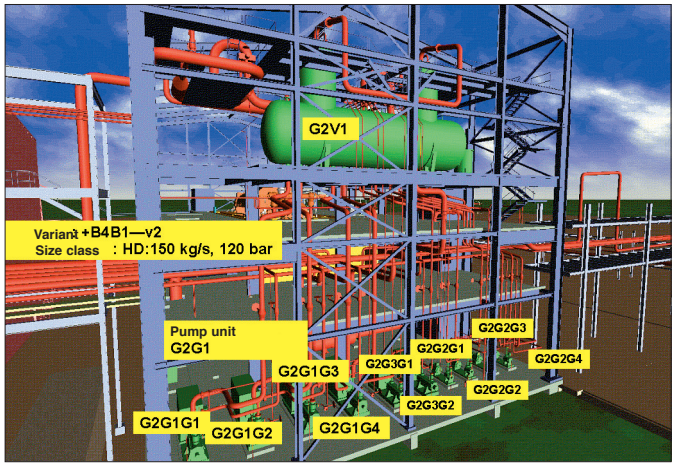


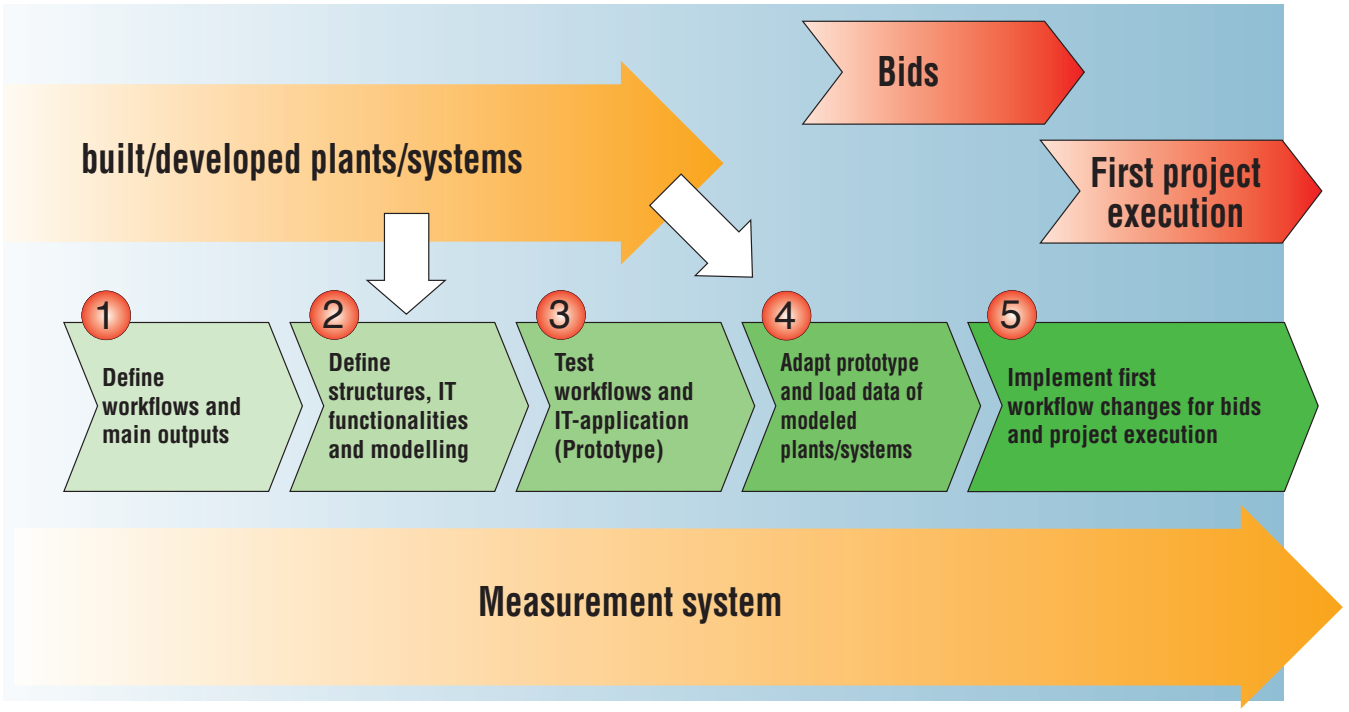
Figure 5: *Erection unit variant + B4B1– v2: Feedwater treatment*

The companies that underwent a benchmarking within a Fiatech study (1,2) indicated that applying engineering reuse provided them with significant competitive advantages. Improvements were made regarding project cycle, costs and quality of their projects. Experience gained from the cooperation in Engineering Reuse has resulted in the following benefits for companies:

- Reduced risk by the reuse of tried and tested solutions. As it is possible to fall back on operational experience when a new design is considered, this will significantly improve the "Fit for Purpose".
- Shorter project cycle time due to a simplified workflow as well as less iteration steps due to faster access to more detailed information on further processing. Besides, the latter allows more activities in parallel.
- Up to fifty percent less work in engineering, purchasing and project management activities if this is the main target. The resources gained from this can be used for additional optimization.

To guarantee success of engineering reuse projects as desired, a long-term vision of the planned use of the methodology in daily business is required. Projects should be given a clear time frame. The individual subprojects should be defined in regard to their general benefit. In addition, a logical order of subprojects has to be planned in order to guarantee regular benefit of the subproject results in daily business.

For the engineering activities with reuse potential defined in the "Project Charter", a clear workflow including reuse and its substantial results should be defined (see figure 6). At the same time, the required reuse structures that will allow this workflow, are to be developed. In a second step the structures will be defined further and more precisely. In addition, plants and systems that have already been built or developed, are



Development *of a prototype to get fast benefits from engineering reuse for bids and project execution*

modelled (mapped) hereupon. The required GUIs, methods and data models will be defined and programmed for the prototype IT application. Step 3 is critical regarding the further acceptance in the implementation step. For the first time, selected engineers from the project execution operation will test the workflow and the correspondingly required IT applications. Step 4 is important for sufficient data to be stored which enables users to make effective use of the system for their engineering tasks. This will substantially increase the acceptance of the methodology. As usual for IT applications, users need intensive and repeated training. Parallel to such a project, the implementation of a measurement system is highly recommended to manage for the success of the project and to make further required improvements more comprehensible.

And now a a few words regarding IT. The correct IT functionalities support engineering reuse, however, they are not sufficient for a successful realization. Those working with this methodology will soon realize that many of the company data are available in multiple but slightly different versions. This kind of project contributes to the generation of a more standardized data model in companies. The new development of a data model is not yet a prerequisite for further progress in engineering reuse. In fact, it is reasonable to base future developments towards engineering reuse on the IT applications available in the engineering to avoid the organization being overloaded with too many changes at once. However, new versions of the applications with more functionalities should be considered to facilitate engineering reuse in the tools (data centric systems). Unfortunately, experience has shown that the range of function of the engineering systems regarding PDM functionality is limited. For realizing engineering reuse on a large scale, however, a PDM application is essential. The first productive prototype with a limited number of users could be realized with a database such as MS-Access, if necessary.

Engineering reuse means a long journey that needs careful planning. The project should be divided immediately into smaller subprojects which allow a fast implementation (three to six months) and which are able to show a benefit.

It can indeed make sense to link an engineering reuse project with a modularization/standardization project if the resources available allow for this. The new structures needed here should be defined as close as possible to the already existing structures such as process units, systems, erection units and their variants. This gets users to accept and finally to apply the additional reuse structures. The key to success is: the consistent realization of the reuse structure in each new plant while the emphasis is clearly on "consistent" and, besides, on the applied tagging system.

The reuse structure furthermore offers the ideal structure to assign plant or system costs. It is therefore reasonable to assign the different cost elements to the first reuse structure from the very first project. This includes, for example, engineering hours, if they are to be reduced, or hardware costs, if companies seek to optimize their plants.

There is no time to lose. If an idea of the required basic functionalities, the amount of data and the number of users is already existing, companies should not hesitate to decide on the IT architecture. Based on this architecture, implementations of prototypes can take place. Experience has shown that it makes sense to keep to the basic principles of the 6-sigma method which means that a project leader experienced in workflow improvement is acting as team manager in an engineering reuse project, that the divisions involved are represented by team members and that an expert with relevant IT experience should also be part of the team. The project team leaders should meet at least once a month to check on the project status and to take corrective action, if necessary, to motivate the team and the organization.

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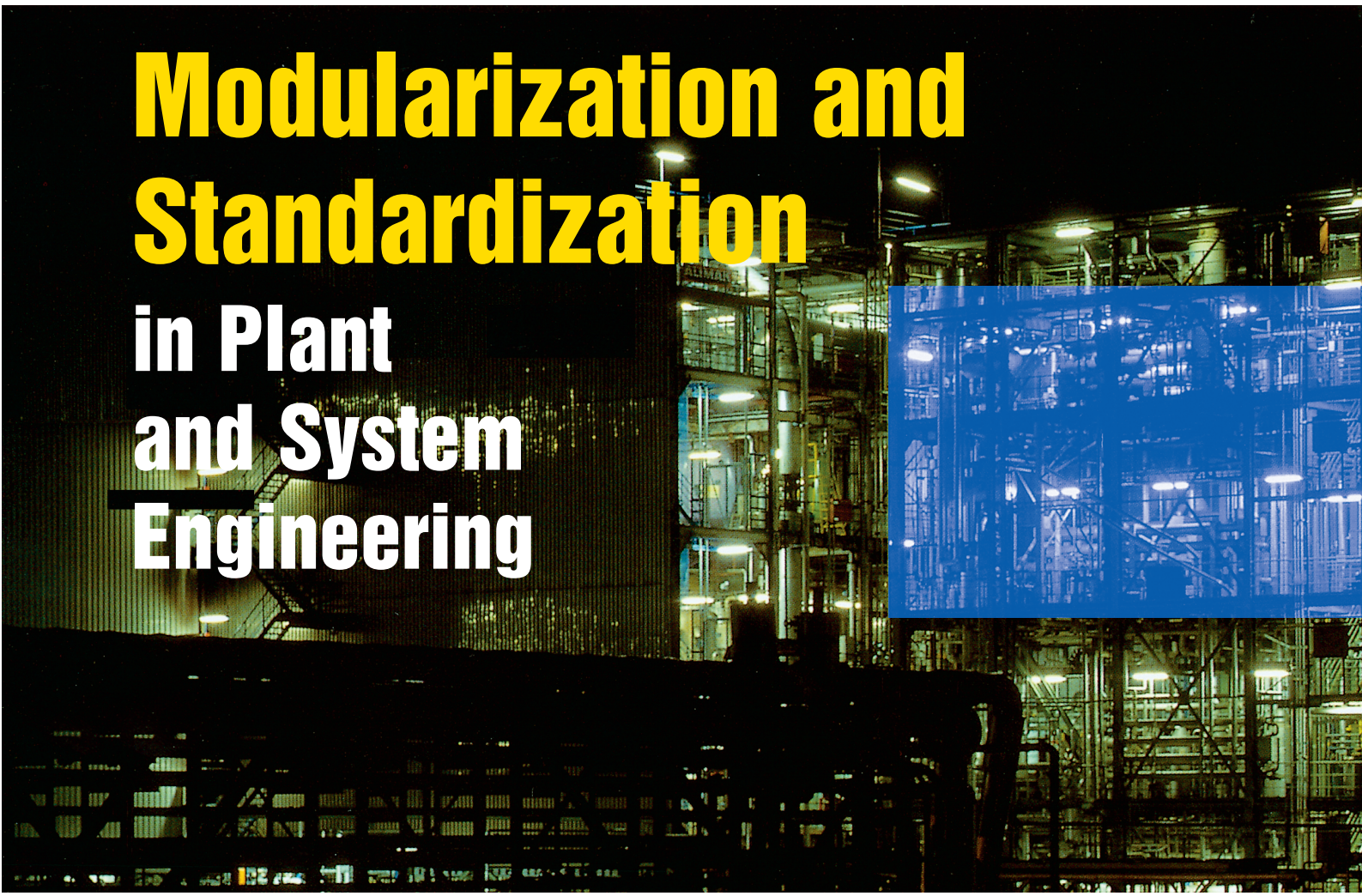
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Modularization and Standardization in Plant and System Engineering



The article presents the methodology of a standardization strategy especially for the development and construction of plants and systems. The aim is to familiarize the reader with the key drivers and possible approaches. Tips on implementation round off the article.

As already presented in the Engineering Reuse White Paper (1), engineering/construction/procurement firms are making use of the methodology of modularization and standardization (M/S) to become more competitive. Impressive proof of the performance capability of this strategy has been provided by various sectors of manufacturing industry such as automotive, aeronautical or machinery. However, the situation in plant and system engineering differs in respect of two important factors:

- the volume produced (only a few plants per year, as opposed to hundreds or thousands of planes, machines or cars)
- the complexity of the different functional requirements and standards of the customer groups.

Although the general principles for savings through economies of scale and scope are of course also valid in the field of plant and system engineering, M/S had found it difficult to enter this area with a lasting effect. The reasons for this relate in part to the markets for plant engineering and system engineering, which for a long time were characterized by national monopolies. Thus it is only in recent years that M/S came to be used for technical solutions through to the level of hardware modules, with the aim of lowering investment costs. The benefits of this can be seen in the reduction in engineering hours, and in reducing costs in production and/or procurement. Depending on the customer segment (each type of customer accepts a particular type of standards), the business model (a particular price policy and adhering to selected standards) and the engineering reuse applications available, it was possible to apply the methodology with varying degrees of success.

Combined cycle power plant as case study. When optimizing the water/steam cycle (see figure 1) for a combined cycle power plant with gas and steam turbines, it can be established relatively quickly that the improvements from one cycle configuration to the next, based on the Net Present Value (NPV) for the plant operator, amount to a maximum of 2 to 3 percent of the costs of investment. However, if a plant can be left as it is ("copy exactly!", as Intel describes in (2)), this results in savings of between 5 and

Glossary

Net Present Value model: profitability model which calculates back the generated annual cash flow (difference between revenues and expenditures) for the plant or system over its economic lifetime, to the year of first being taken into operation (using weighted average capital costs)

Learning curve: graphical display of the cost reduction achieved on the basis of experiences, or reduction of errors, e.g. through improved manufacturing processes. The learning curve is shown as a function of the cumulative products produced (most often with a logarithmic scale). It is sometimes also described as the "experience curve" or the "Boston effect". A very graphic example is the reduction in the assembly time required for an Ikea chair (well known in Europe), comparing the first with an identical second chair.

20 percent, depending on the effects of the doubling of the number of plants (the "Boston effect"). Admittedly, in reality changes are generally necessary due to different requirements or new technologies being used. The total achievable savings are influenced by the suitability for purpose of the modules and standards developed, the reusability of documents and models (contracts, specifications, drawings, 3D CAD models etc.) in the execution workflow, and through to the supplier. Experience shows that good M/S can be achieved if the reciprocal influence of the following five drivers is taken into account:

- defining the application ranges and focusing on the economically attractive ones
- optimizing technical solutions
- standardizing technical solutions
- defining modules, optimizing their content and interfaces
- exploiting learning curves

These key drivers are described in detail below. Figure 2 shows an example of how a reduction in the application range can lead to noticeable cost reductions, but without noticeably impairing the achievable market volume. The challenge is to identify, for the plant to be modularized/standardized, the range in which a functional requirement such as the ambient design temperature has an impact on costs, and the range where there is hardly any influence on costs, whilst having a large influence on market volume. For example, in considering the Heat Recovery Steam Generator (see figure 1) with the specified gas turbine type, it was found that for different ambient design temperatures the Heat Recovery Steam Generator should be copied exactly, in order to achieve the full cost reduction through exploiting the learning curve. With another power plant supplier, certain modifications were made to the superheater tube bundles in order to reduce the costs at higher ambient design temperatures. Accordingly, the learning curve could only be used for a lower market volume.

A further example. Should the equipment or machines for a chemical plant be installed precisely for a fixed throughput, or should they be able to cover a certain range of possible throughputs? If the share of costs for engineering and work preparation for this is substantial by comparison with the costs of materials, then it is sensible to divide up the throughput ranges into size classes. For each size class, there should only be one product size. It is also worth mentioning here that with smaller plants more should be modularized and standardized, because the administrative and the engineering costs are higher by comparison with the hardware costs. Additionally the benefits of optimization are smaller in absolute terms with smaller plants.

Figure 3 is a model showing how the technical solution is optimized for a particular target market segment. It involves comparing possible known solutions with regard to investment costs and performance with factors affecting profitability such as the costs of fuel, electricity prices and weighted average cost of capital in the target market segments, using the NPV method. This approach is practically the same for power plant buildings and for chemical or petrochemical plant buildings. The improvements realized were of the order of 15 percent of the NPV in a chemical plant building and around 3 percent for a power plant building.

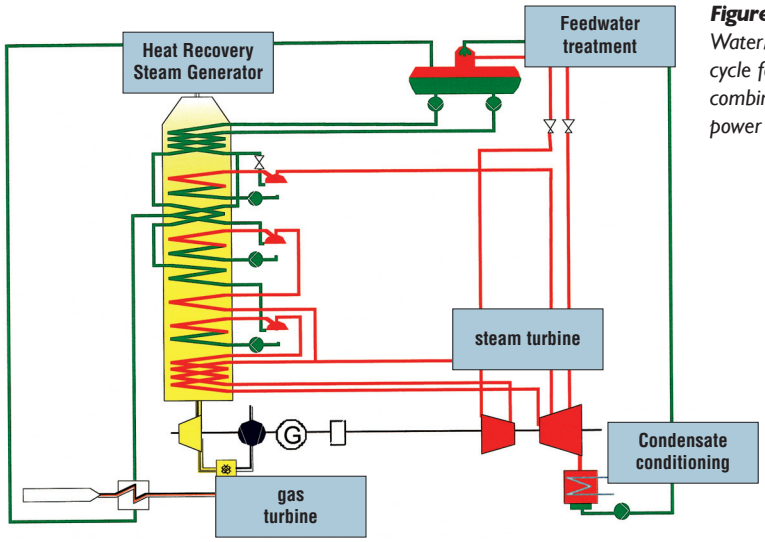


Figure 1: *Water/steam cycle for a combined cycle power plant*

Figure 4 demonstrates how the reuse of an optimally standardized technical solution results in a higher NPV for the plant operator. Let us take the example of a water/steam cycle with triple pressure without reheat for a combined cycle power plant, that was selected in optimizing the technical solution for the target market segment (based on the criteria of average fuel costs). Given the cost savings through reuse, this solution can also be more suitable in a different market segment (high fuel costs) than the technical solution with a higher efficiency (triple pressure with reheat) which would probably have been the optimal solution for that market segment. The choice of a standardized water/steam cycle can result in the Process Flow Diagram (1) being the same for the scope, and accordingly the associated Piping & Instrumentation Diagram and the 3D CAD model (1) can also be the same.

No magic solution. Figure 5 is a model showing that while increasing the content in the modules leads to lower costs with reuse, it can also mean that the achievable market volume reduces as a result. Let us look again at the example of the Heat Recovery Steam Generator. For the first power plant supplier, the Heat Recovery Steam Generator was a module which was intended to contain exactly the same hardware from one project to the next. For the second power plant supplier, the module was sub-divided into:

- the superheater tube bundles, which formed a separate module adapted depending on the ambient design temperature
- the other components (ducts, steelwork, pipes, valves, and other tube bundles) formed a further module

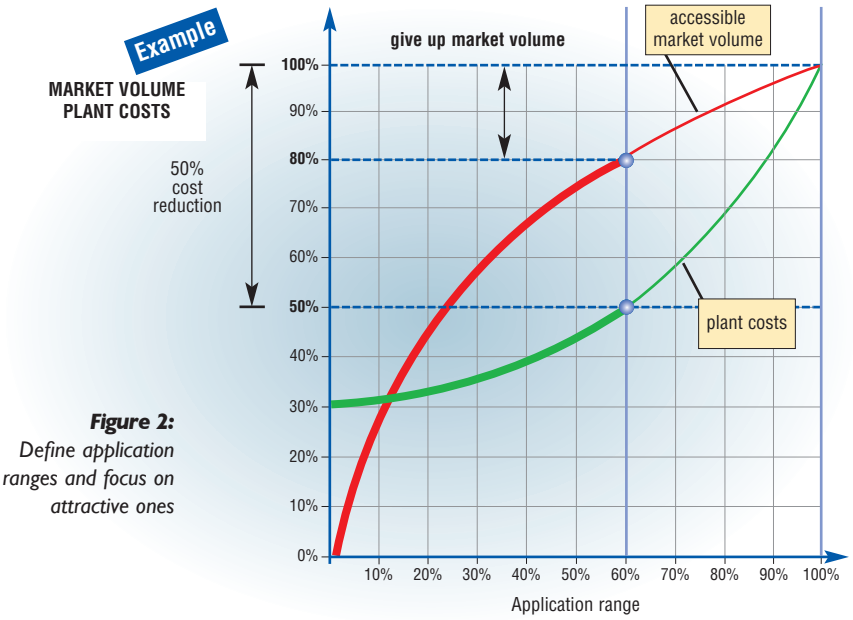


Figure 2: *Define application ranges and focus on attractive ones*

Example

Alternative solutions

- Dual pressure cycle
- Triple pressure cycle
- Triple pressure reheat cycle

Target market economics

$$s = \frac{\Delta \text{ cost (\%)}}{\Delta \text{ efficiency (\%)}} : 1.5 - 2.5^{1}$$

[1]) for equal plant project Net present value

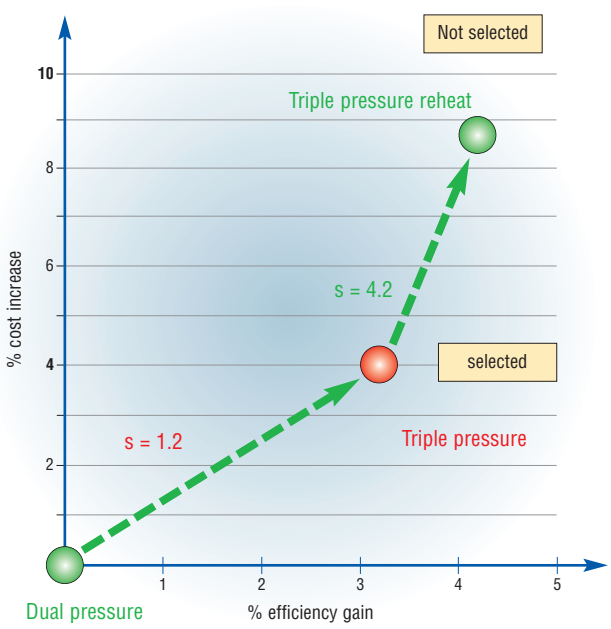


Figure 3: *Optimize technical solutions*

Accordingly, the savings from reuse were less for the second power plant supplier, but the costs for the power plant at higher ambient temperatures were lower to offset this. Optimizing these effects within their specific business environment has resulted in these two power plant suppliers choosing different modularization concepts. In a modularization project, the focus is also on defining the modules, their content, their interfaces, and also their size classes for the chosen product segments. In the example above, only a single size class was specified, which was determined by the type of gas turbine.

Figure 6 illustrates exploiting the learning curve with validity for an entire plant, or also with validity for only a single module. In plant/system engineering, so far these learning curves have barely been measured or specified as an objective – unlike in airplane manufacturing, for example.

It pays off. The companies which were carrying out M/S projects indicated that they were able to achieve cost reductions of between 10 and 20 percent, calculated using the NPV method. Half of these improvements came from improving the technical solution for a market segment, and the other half from reusing hardware modules and accordingly also reusing engineering services, i.e. exploiting the learning curve. Indirect improvements with regard to project throughput time of around 25 percent were not uncommon. Here, too, a measurement system is of major importance to bring to light both progress and problems (2).

Example

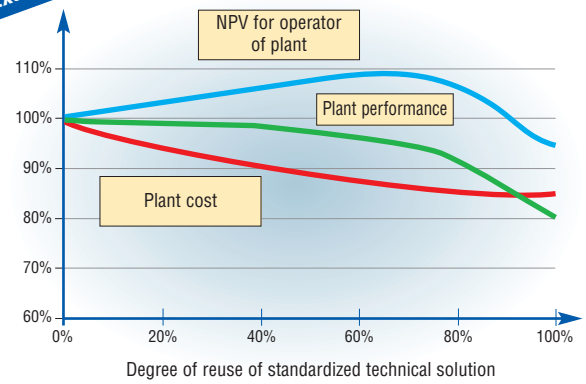


Figure 4: *Standardize technical solutions*

In order for an M/S project to lead to the success desired, a clear scope needs to be defined which is based on the most attractive market segments or product segments. A clear time frame should be specified for the project.

Figure 7 shows the general approach. For the areas, which have been defined, in a first step a quantitative analysis is made of:

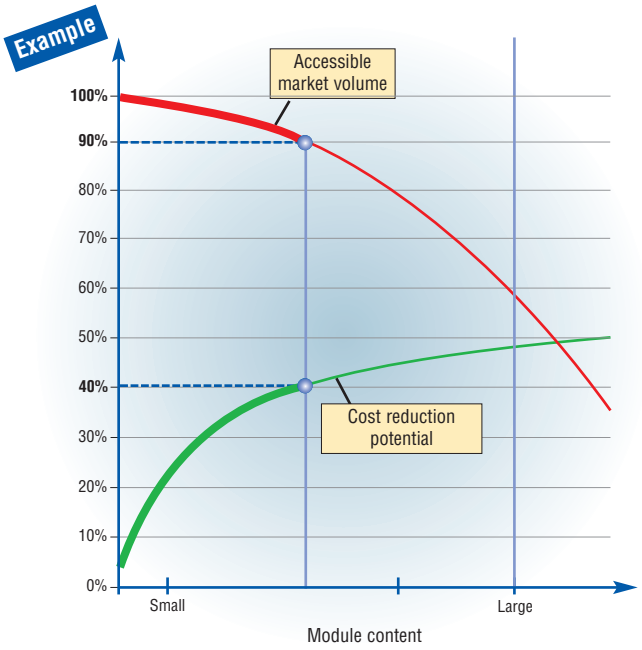
- the functional requirements needed in future, including cluster analysis of requirements which have an influence on modularization
- the size of the market which stands behind the cluster requirements.

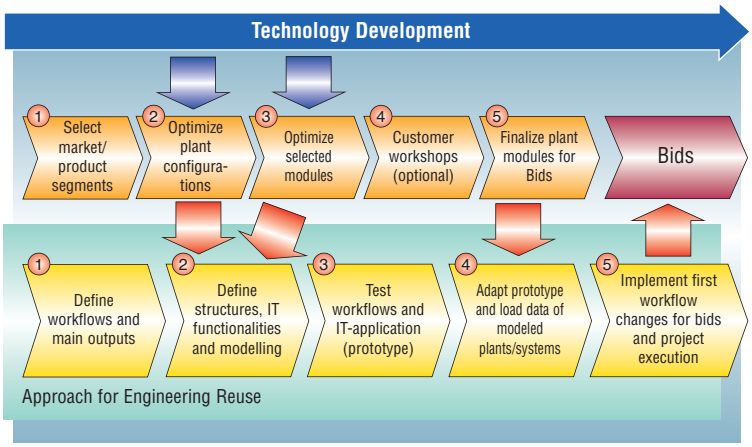
A comparison with the plants which have already been built can be helpful. In parallel with this (step 2), the mutual interaction of the different requirements, such as fuel costs, are calculated with the plant configurations, e.g. triple pressure for the water/steam cycle, and the key parameters for the equipment, such as live steam pressure and temperature. For this, the costs and the performance characteristics of promising configurations and equipment parameters are examined and compared in a NPV model. The analysis of customer requirements of the initially defined market segments and their impact on the optimal plant configuration and equipment parameters, combined with the expected cost savings from the five drivers, make it possible to define plant configurations which appeal to larger market segments. The aim is therefore to reduce the number of options as far as possible, in order to achieve fewer product segments. Each product segment is defined by its optimal plant configuration and the associated equipment parameters.

At the end of step 2, modules are defined which occur in different product segments, in order to tap into further potential cost reductions. In the third step, the individual modules such as Heat Recovery Steam Generators for a combined power plant are looked at in more detail. The procedure is similar to that for plant configurations: as far as possible, attempts are made to reuse modules – if necessary, by creating sub-modules from one product segment to another. This is carried out at hardware level, because this offers the greatest savings potential. Here again, the challenge is to optimize the design. For example, on the Heat Recovery Steam Generators it was possible to save a total of 10 percent of the costs through a new thermal design of the tube bundles and through integrating different functions "transport ancillary" (bracing) and "flue gas casing".

At this level, it is often necessary to choose between "over-design" (in order that the module can be used for a larger market volume) and the savings from exploiting the learning curve. This optimization is also carried out using a NPV model. The result is an even more accurate definition of the modules, sub-modules and possibly sub-sub-modules, their reuse strategy and the size they can accommodate. It can also be a sensible approach to develop a parametric design model for a specific module, for example in those instances where the hardware costs with over-design weight more heavily than exploiting the learning curve.

Before the M/S concept is definitively implemented, the concept and the proposed new designs need to be checked using the Voice of the Customer. We recommend five workshops lasting one to two days per customer – depending on the complexity of the system/plant. The customer makes available a multi-disciplinary team, and a selected collection of design options are presented. These are assessed using a modified "Quality-Function-Deployment (QFD)" methodology. The outcome can certainly produce surprising results: for example, after one such meeting the technical solution favored by the power plant supplier, involving a fast-rotating high-pressure and medium-





Source (all): Author

Figure 7: *General Approach*

Figure 5 (left): *Define modules, optimize their content and interface*

pressure steam turbine, was rejected due to a lack of a convincing reference for its gearbox size.

The customer feedback therefore makes it possible to assist the M/S plant/system in achieving greater acceptance and to ensure a successful launch. These workshops also provide important suggestions as to the content of the communications which should accompany the launch of the new plants/systems.

What we have learned. Like engineering reuse, M/S is a continuous process:

- customer behaviors change (national companies which become globally operating companies)
- new technologies lead to different plant configurations or changed modules
- new manufacturing processes which have a different influence on the learning behavior can also lead to different modules and reuse strategies

The proposal should be focused as quickly as possible on a single plant or system type, so that it can be rapidly implemented (in a time-frame of around six months) and the benefit demonstrated. This helps in bringing those who are skeptical about M/S in the company on board. If resources permit, it makes sense to combine an engineering reuse pilot project with an M/S project.

Experience shows that even for M/S projects it is sensible to respect the principles of 6-sigma projects. Team members from Sales/Marketing, Development, Engineering, Procurement and Cost Estimating should be represented. If the company operates on a global footing, it is also important to include those with regional responsibility within the company. The most experienced engineers are the ones who should be involved in the team, so that the results which emerge are not again called into question in the course of "daily business". The team members should view the M/S project as having the highest priority. Otherwise there is a risk of the project being delayed by operational business and possibly losing momentum for implementation. If this cannot be guaranteed from the organizational point of view, it is better to accept delays than to forego using the experienced team members. The use of an external consultant is sensible in order to contribute additional expertise and other viewpoints to the project, to keep it better on track. The external expert is a support if there is a need to win people over to the project, which is especially important where there are trans-regional teams or very functionally oriented organizations.

The project steering committee should commit at least an hour once a month to directing the project and giving the team the necessary impetus to progress. This is especially important since a rethink-ing process needs to take place amongst the management team. If not, there is a risk that everything will be sold apart from the M/S results, developed with the great effort of the M/S-team, often working through the different opinions and strong beliefs. The results of the customer workshops can be very helpful for this necessary work of winning people over to the new ideas.

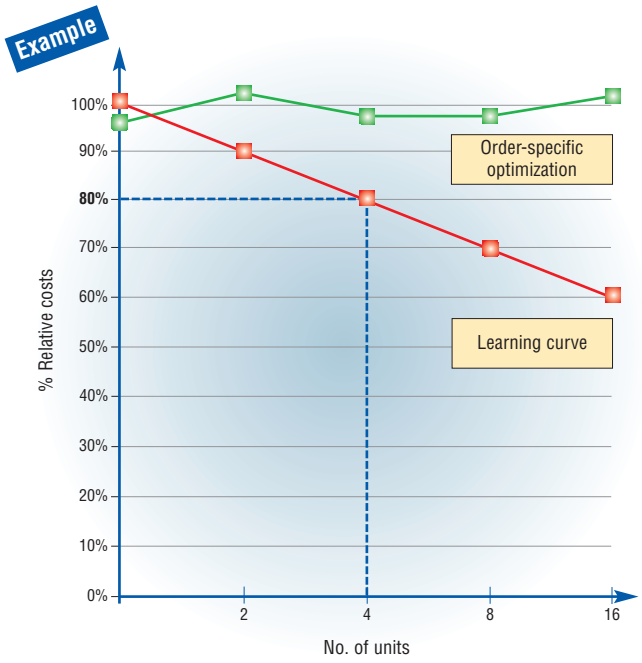


Figure 6: *The more reuse effects can be generated, the steeper the learning curve will become (5 - 20 %).*

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