Human factors engineering in petrochemical projects: Part II

Among the subjects in this second article on the place of human factors in project planning, the project business is analysed – discussing how ergonomic princples should be integrated – and the framework of a warranted quality system, including management monitoring tools and system auditing

Martin E J van Uden and Harrie J T Rensink
Shell International

Although the man-machine interface in petrochemical manufacturing projects has always been considered to be an integral part of a sound engineering design, many ergonomic misfits in operability and maintainability have been experienced after implementation. Based on that experience a vision and policy was formulated, which resulted in a human factors engineering strategy integrated in the front end loading (the early development phases) of the business process of project preparation and execution.

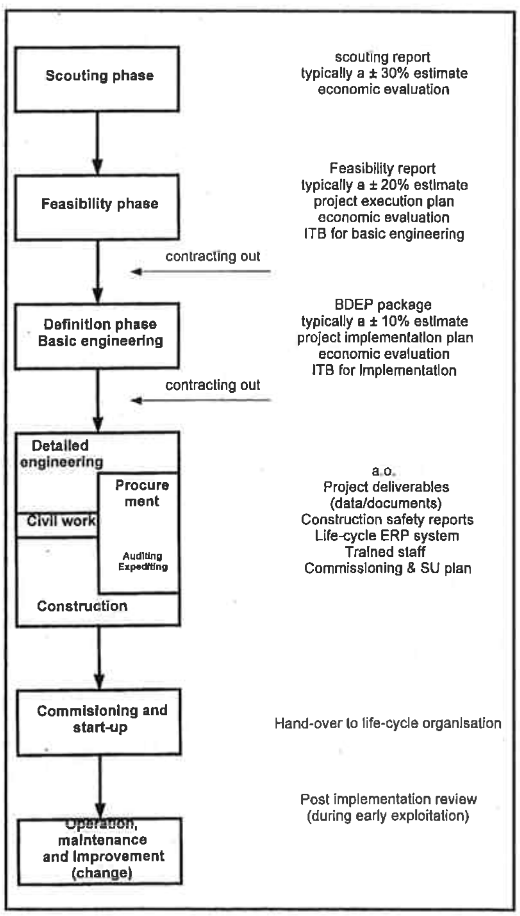

***Figure 1** Typical high level business process description: "Project preparation and execution instruction"*

The benefits of this strategy are identified both in business terms (economics) and in working conditions; like improvement in Health, Safety and Environmental (HSE) aspects. Based on historical data it is now identified that for a typical $400 million petrochemical project the strategy can result in a reduction of: 0.25 per cent of capital expenditure (Capex), 1 per cent of the total engineering hours, and 3 to 6 per cent of operational and maintenance life-cycle costs of facilities (Opex).

Part I of this article, published in the Summer 1998 issue of *PTQ*, described the development of the strategy starting with creating awareness within an organisation up to the general approach based on a developed vision and policy. Part 2 gives the reader insight in the actual project management and quality assurance of human factors engineering in petrochemical projects.

The statements that human factors and ergonomic principles are not sufficiently anchored in the design process is not worldshaking. However, especially for projects in the petrochemical industry, a clear recipe cannot been found in literature – much has been written but an incorporated control system has not been found.

Design process

After the birth of an idea to invest in a petrochemical plant, either for economic or other reasons, a conceptual design is made, on the basis of existing, improved or new technology. The conceptual design is normally followed by a study into the feasibility of the project and an early (economic) evaluation will indicate whether to proceed with the basic engineering study, during which the project is further defined in terms of scope, implementation and financing. The so-called basic engineering and design package (BDEP) or project specification (PS) contains enough information to make an accurate cost estimate (accuracy normally plus or minus 10 per cent).

At this point business premises and forecasts are frozen and an economic evaluation, including technical and financial risks and sensitivities, is performed. In most petrochemical companies this evaluation is the basis for approval of the project. During this front end engineering phase typically some 5 per cent of the capital is spent. After approval of the project the implementation phase is started, including the detail engineering, during which the equipment and material specifications are described in requisitions, being the starting point for the procurement.

During detailed engineering, drawings (now usually based on data) are produced to enable the constructors to build the petrochemical facility. Two dimensional computer techniques have been increasingly used and during the past decade graphic oriented 3D computer imaging has been used, while today 2D and 3D design is integrated on the basis of object oriented design and engineering. Virtual reality is commonly used on the construction side as well after construction of the new facility is tested and started up.

This process, as described, can be shown schematically in relation with time, showing the deliverables of each process step, as shown on the right hand side in Figure 1.

Input of engineering disciplines in the design process

During the process of design, engineering, procurement and construction, many engineering disciplines are involved, such as process technologists/engineers, mechanical, electrical, civil and instrumentation engineers. Cultural, strategic, and logistic considerations give a continuous input during the design process, resulting in decisions mostly influenced by conflicting arguments or constraints. Often the capital investment must be incorporated into existing infrastructure and, especially in recent years, much capital investment is spent in retrofitting and debottlenecking existing units.

Good engineering is considered when all disciplines mentioned are working integrally and where mutual empathetic behaviour is shown. Although it is sometimes said that this is the project manager's role, we have noticed that the system (organisation and availability of the correct procedures and culture) in which the responsible project manager has to work is of determining influence to success.

Budget constraints (foreseen or unexpected) are a handicap in good integration between the disciplines as it is often thought that this is in conflict with proper engineering, procurement and construction.

It should be noted that many petrochemical companies have slimmed down their engineering strength, relying more and more on the aid of engineering contractors. Although this is attractive from a staffing point of view there are some penalties.

Engineering contractors do not operate the plant so do not obtain enough feedback, as a company engineer would, to improve the level of engineering skills with respect to anticipating life-cycle operations, maintenance and other risks. Therefore, and depending on the type of contract, ECs are not always too interested in the plant's life after construction has finished.

These constraints definitely influence the quality of the projects.

Lack of user participation in design

Some important participants in the project have not been mentioned yet. This important group of potential contributors to the design are often not involved during the design process, or come in too late or only in order to submit comment. Yet they are the very ones who have to operate and maintain the plant for many years to come.

Of course, these end users were always recognised as participants in a project, but more in the sense of giving comments on a design or a document. Seldom have they been recognised as really contributing to the design as a demand defining participant.

From interviews with designers, engineers, constructors and project managers as well as operators and maintenance workers it can be concluded that there is a difference in attitude between the two groups, in that the first group is motivated to deliver a product that fulfils the basis of design and who concentrate on those issues and the end-users who are motivated to operate and maintain the plant in an efficient and effective way and are more concerned with the life-cycle.

The attitude of the engineer can be generally summed up as: "As long as it's working I did a fine job". Operators and maintenance workers, on the other hand, complain that they need more effort to do their job during the exploitation as a result of user unfriendly designs. They also claim that this increases exploitation costs. The fact is that if end-users, as the representatives of the operator/ owner, are insufficiently involved during the design and construction phases, this results in a negative influencing factor – what is generally identified as limited "client commitment level" (CCL).

However, a new dilemma exists in view of the availability of operational and maintenance staff during the design, and methods should therefore be developed to overcome this.

Problem definition

Ergonomics or human factors engineering is easily forgotten during all phases of a project (refer to Part 1 of this article). This leads to many disadvantages, among others, extra costs during the

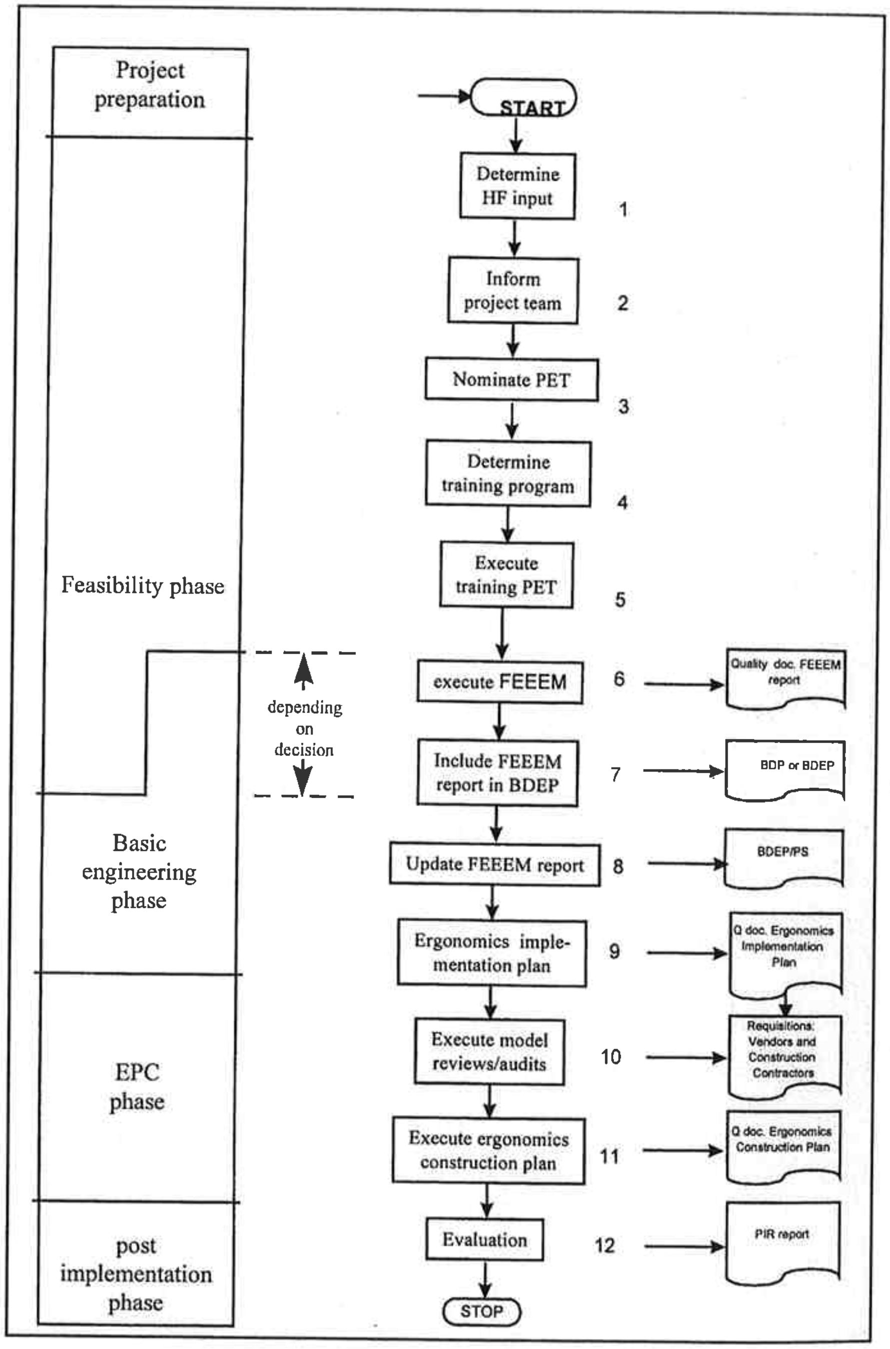

Figure 2 Business process flow diagram

further life-cycle of the plant for operations and maintenance, and additional health and safety risks. Furthermore, those who might contribute to avoid ergonomic misfits are not often consulted.

Not enough emphasis is paid to the many tasks which have to be done when the plant is in operation and has to be maintained. It can be concluded that the design process should have incorporated more means to ensure the knowledge of ergonomics, human factors engineering, and task analysis, of which the results have influence on the design and user participation.

Too many ergonomic misfits exist in petrochemical plants, even those recently built after making use of graphic but static oriented 3D computer programs.

This is due to the fact that project and design organisations and their engineering contractors have not the appropriate business controls in place to make sure the defect is addressed properly. Furthermore, those who might contribute to avoid ergonomic misfits – the end-users of a work system – are not often consulted.

This can best be achieved by an ergonomic awareness programme for all those involved in projects, through organisation and management procedures and, last but not least, by showing the economic and non-economic benefits of human factors engineering in projects. The application of new simulation tools based on data-centric and object oriented, and thus 2D/3D integrated (dynamic) engineering systems – which have a proven history in the automobile, aircraft and shipbuilding sectors – will lead to simple and early 3D simulation of the plant under design. This leads to better understanding of an early "designing out" of ergonomic misfits as well as optimised life-cycle oriented designs.

Procedure to follow

In this procedure, the human factors engineering activities, as experienced in a number of recent projects, are described in relation to the project phases. On the left hand side of Figure 1 the status of the project is given, ranging from the feasibility phase, through the definition (basic engineering) phase into the detailed design, procurement and construction phase. It may be noted that, early in the design, ergonomic demands have to be specified, the main reasons being:

—It is in this phase that inside battery limit (IBL) operational and maintenance philosophies are being defined

—The design is still flexible in its scope definition, so that ergonomic demands, especially on IBL philosophy level, can easily and at no cost be integrated in the design

—Demands and scope ergonomic categorisation can be set for use in the basic and detailed engineering phases.

The business process flow diagram, shown in the centre part of Figure 2, indicates the scope, purpose, organisation and management of human factors engineering in projects. Keywords in this procedure are: Plant Layout, Human Machine Interface design, Control Room and Human Computer Interface Design, Ergonomics, User Participation, Client Commitment Level, Operability, Maintainability and System Reliability.

The purpose of this procedure is to integrate the user's requirements into the design of a system at the right time, well in balance with the technical and economical constraints, with respect to project investment as well as life-cycle cost savings and occupational health and safety benefits. In doing so, the design will also reflect the way the future operators and maintenance people will utilise their system effectively while at the same time understanding that impossible demands are not implemented.

The procedure in general leads to lower capital expenditure as well as lower life cycle costs of installations and costs of plant change [Managing human factors engineering in projects procedure; doc ID EMIS PMQ.01, Shell International, The Hague].

Executing a human factors task analysis in basic design and/or definition phase is crucial for catching the technical/usability requirements of the human machine interfaces early. After these requirements are identified and recorded, there is a standard approach to follow during the succeeding phases.

This procedure is applicable for new grassroots projects as well as for brown fielders and debottlenecking or major retrofitting. The procedure demands cooperation between operations/maintenance, process engineering, project management, construction management and the engineering contractor. Discipline engineers normally do not participate during the analysis or audits but are consulted along the road.

The policy with respect to human factors engineering is geared towards achieving an optimal human machine interface for installations, control rooms, work places, laboratories, and offices. It is essential that the persons who are ultimately responsible for ensuring a user friendly design are the designers, engineers and project managers executing the project; they need the input of life-cycle users in time to avoid later changes during detailed engineering or, even worse, during construction.

A good quality control is guaranteed when there is proof in the form of deliverables, sometimes integrated in general reports, like BDEP packages or project specifications. The type of deliverables is indicated on the right hand side of Figure 2.

> "Too many ergonomic misfits exist in petrochemical plants, even those recently built after making use of graphic but static oriented 3D computer programs. This is due to the fact that project and design organisations and their engineering contractors have not the appropriate business controls in place"

Identify necessary human factors engineering input

The person responsible for putting together the Basic Process Design Package (BDP, often called BOD) and/or the Basic Design and Engineering Package (BDEP) – frequently the process engineer or the project co-ordinator/manager – should discuss and evaluate the necessary effort for the project with the human factors engineer.

Inform project team/manager/kick-off meeting

The process engineer informs the project team leader or manager about the proposed strategy, including the initial costs (it is assumed that the project team leader or manager is an experienced professional and relates the initial costs to the benefits to be acquired later, although, many times, the challenge from the project team leader indicates differently. The agreed human factors engineering plan of action is then part of the agenda of the project kick-off meeting. Within larger projects (above $50 million) the human factors engineer often plays a coordinating role

Nominate the Project Ergonomics Team (PET)

The person responsible for drafting the BDP and/or BDEP should nominate (in consultation with the appropriate discipline managers) the participants of the PET. The Project Ergonomic Team normally consists of a (lead) process engineer, participants experienced in operations and maintenance, sometimes specialists (mechanical, instrumentation) depending on the type of project, "In the case of control room or re-instrumentation projects the management of information needed for graphical display design is of utmost importance to achieve an effective human computer interface, along with the more traditional design tools, such as link analysis methods"

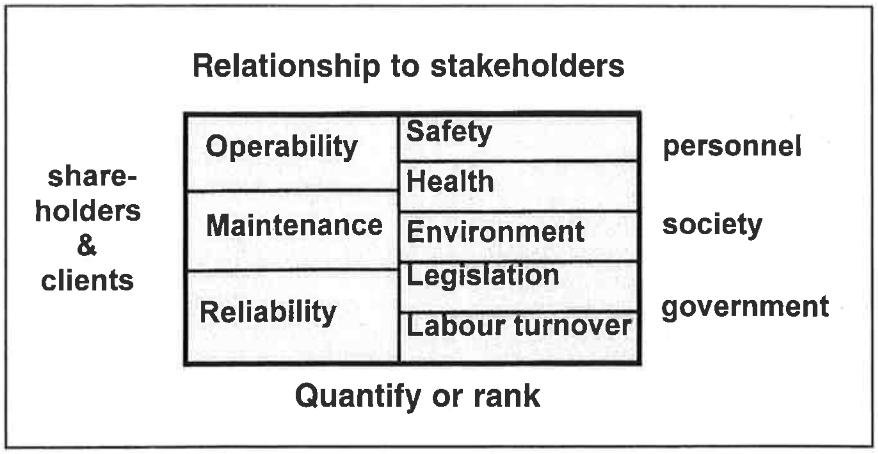

Figure 3 High level benefit areas in relation to main stakeholders

and the human factors engineer.

Decide the necessary training for the project

It is necessary to decide what kind of training is appropriate for the project, based on the project scope and the competence of project participants. For example, before the execution of the Front End Ergonomics Evaluation Matrix (FEEEM) design analysis, it is necessary that the nominated participants of the PET meet several criteria:

Operations/maintenance personnel should have followed a training module focussing on their function within the PET team [Workshop ergonomics in process installations; ID EMIS IT 03 Shell International, The Hague, and Ergonomics training module for operators and maintenance workers; ID EMIS IT 05].

Process engineer/discipline engineer and project manager should have participated in a full scope human factors competence improvement training, focussing on cost/benefits and implementation procedures with respect to management of human factors engineering during all phases of a project. It should be considered to have engineering contractor and/or vendor representatives participating during ergonomics workshops, if relevant. The human factors engineer will co-ordinate the execution of the training requirements as specified in this step. Normal training ranges from four to eight hours.

Execute FEEEM design analysis

This analysis should be implemented by the PET according to the procedure. The FEEEM design analysis describes a multidisciplinary task analysis method to be applied during feasibility or definition phase to evaluate potential ergonomic bottlenecks in the design. This procedure is part of the Pernis Projects Quality system [FEEEM design analysis; ID EMIS PMQ 02, Shell International]. A standard part of this design analysis is implementation of the Identification of Valves Analysis (IVA) [IVA; ID EMIS PMQ 2A]. The results of this design analysis along with the IVA are documented in the FEEEM report.

Also, the strategy with respect to implementing ergonomics in long delivery items and (critical) skid packaged units should be part of the report [Best practice ergonomic guidelines for skid package units design; ID EMIS VM 01].

In the case of control room or re-instrumentation projects the management of information needed for graphical display design is of utmost importance to achieve an effective human computer interface, along with the more traditional design tools, such as link analysis methods aiming at an efficient control room building layout for human efficiency improvement during normal and emergency operations.

Include FEEEM report in the BDP or BDEP/PS document

The person responsible for coordinating the BDP or BDEP/PS document incorporates the FEEEM report into the BDEP document. At the end of the BDEP phase the FEEEM report will be updated and the resultant actions derived by it should be verified in relation to the scope of the BDEP/PS and integrated into the initial plot plan.

Ensure that analysis results – for instance identified "soft boxes"of critical maintenance or logistic routing – are integrated in the plant lay-out.

Determine Ergonomics Implementation Plan

At the end of the BDEP/PS phase the Ergonomics Implementation Plan is set up during detailed engineering, procurement and the construction phase to secure the requirements and demands resulting from the FEEEM analysis. For projects of less than $5 million Capex, it is generally sufficient to include the FEEEM report in the Project Execution Plan/Project Implementation Plan. The project manager is responsible for the execution of the Ergonomic Implementation Plan.

Execute model reviews/audits

To ensure that the ergonomic requirements are met within the project, a 3D CAD model review is used during 30, 60 and 90 per cent of the detailed engineering phase. Critical operations and/or maintenance activities should be simulated (preferably dynamically) during detailed engineering, making use of new technologies in order to check the operational and maintenance procedures as indicated in the FEEEM report.

Impressively constructed procedures do not always work and have to be modified because of safety and health risks and costs. Dynamic functional simulation is becoming available and will be used more and more. Special attention should be given to skid packaged units.

Execute the Ergonomic Construction Plan

This plan's purpose is to guide the construction contractor through installation of "field run" equipment, which is not always shown in the physical computer models, but only in the functional models. This concerns mainly field run installed items like small-bore piping, lighting fixtures, secondary cable trays and so on. The plan normally includes :

—Inserting ergonomic requirements into standard paragraphs of contracts with installation contractors, including procedures for handling diagnosed misfits

—Awareness sessions with onsite contractors

—Use of physical (3D) models onsite for reference

—Execution of ergonomic verification rounds.

Evaluate the application of human factors engineering

The human factors engineer, the project

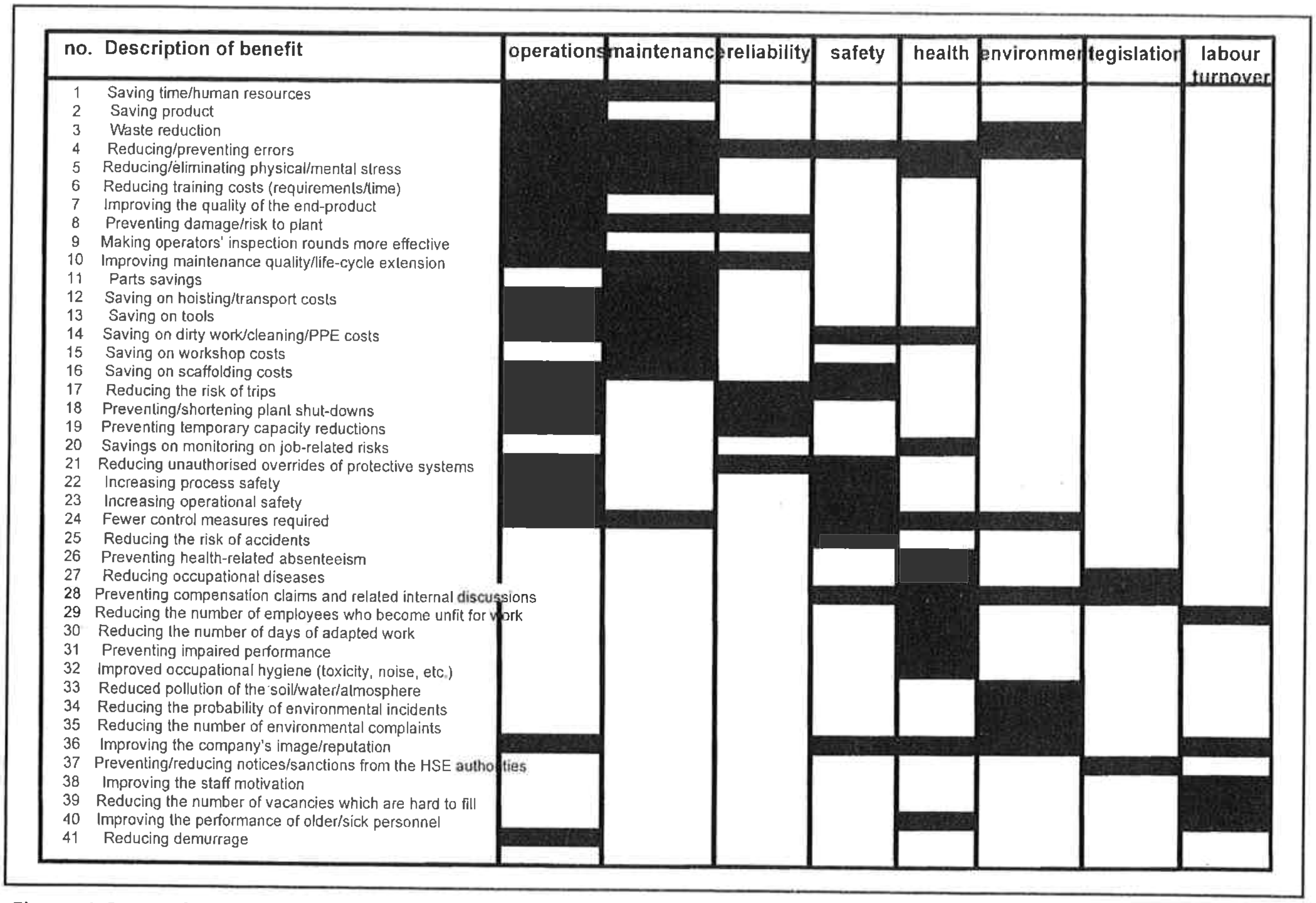

Figure 4 *Cross reference benefit table*

manager and/or client's maintenance manager normally will decide to evaluate the successes or failures of the ergonomics programme during the post-implementation period.

Cost and benefits

Showing programme costs and benefits normally motivate professionals to apply or not apply programmes. To demonstrate the benefits of implementation with respect to costs, an extensive study was done into the cost and benefits items by Shell Nederland Raffinaderij and Shell Nederland Chemie at Pernis and Moerdijk, in cooperation with Nederlandse Aardolie Maatschappy Assen some three to four years ago [Benefits of ergonomic design; Part 1 Quantification model, Part 2 Case studies; ID EMIS PMQ 07].

Generally, it was found that benefit/cost ratio for new (grassroots or brown field) projects are high, but also that in debottlenecking or retrofitting projects the balance between costs of analysis and their benefits for Capex and life-cycle exploitation costs are still very favourable. More critical were small projects or so-called plant changes – normally paid directly out of the exploitation budget – which were meant to abandon ergonomic misfits existing in plants in operation. Justification of such investments was often made on rather uncertain grounds, based on a kind of common sense and understanding rather than by economic or other calculations. It was believed that a model able to discriminate between justification or not of these types of exploitation costs could also be used for the larger grassroots or brown field projects.

Benefit areas

As costs can normally be estimated up front on the basis of scope and hours, the team first concentrated on the benefit areas. Three levels of benefit areas were established. The high level was defined at stakeholder level, a rough definition of a stakeholder being anyone or any group sharing the costs and other disadvantages and/or benefits of the business.

Figure 3 is a graphic representation is of the high level benefit areas in relation to the main stakeholders.

The next level was determined by investigating the benefits, tangible or intangible, within the main (high level) benefit areas. It appeared that many second level benefits were found to benefit more than one of the main benefit areas. A cross reference graph was constructed, which became the foundation on which the benefit identification process was built.

This cross reference benefit table, given in Figure 4, is an example of how benefits are ranked. A third level of benefits is a long checklist, belonging to each of the second level benefits on the left hand side of the figure. This third level of benefits is of great help in identifying benefits, which are then classified in the matrix shown.

After identification, the benefits need to be quantified. If it is possible for them to be estimated, the benefits are outweighed against the estimated costs. In many cases, however, the benefits are rather intangible, eg "What is the dollar value of safety? ".

In cases where no tangible figures can be derived from the benefits, the benefits are simply ranked according to a system valuating:

—The exposure class, showing the risk of exposure. This exposure class is determined taking the frequency of the task to be judged and the number of exposed people into account

—The effect level, showing the effect on people, environment, etc, should the task fail.

—The total risk factor, being a ranking

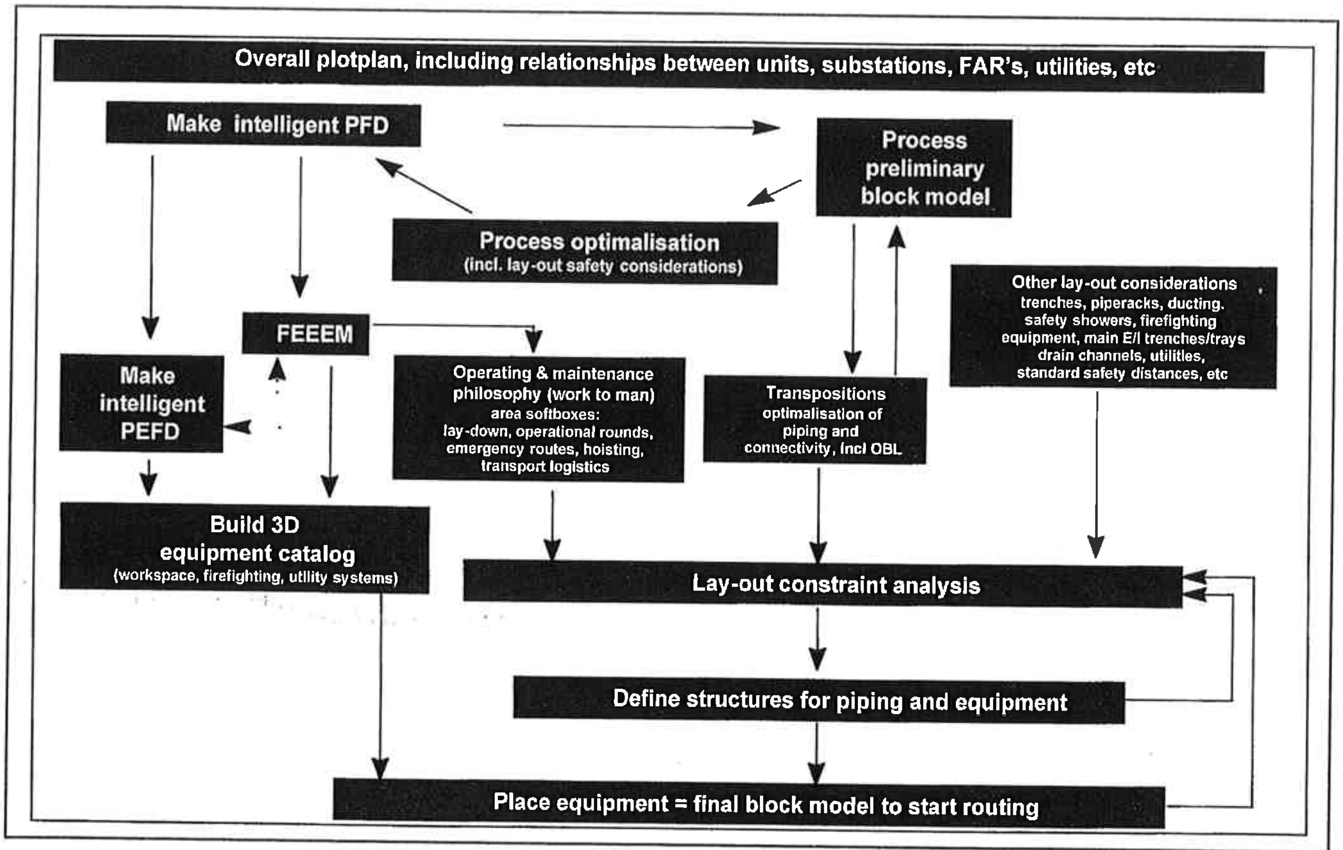

Figure 5 *Example of ergonomics integration*

on basis of the exposure class and effect level.

Costs and ranked or quantified benefits

As mentioned above, benefits with a tangible content may justify the cost of ergonomic improvement in existing plant or in design. When a ranking exercise is needed only the highest risk factor is used to determine the payout criteria, which have been agreed beforehand with management. So for intangible benefits, only the benefit with the highest classification counts, while for tangible benefits, benefits in dollars can be added.

The payout criteria are also dependent on the height of the costs. If payout criteria are reduced to zero a full intangible benefit has justified the costs. In most cases there is a combination of intangible and tangible benefits, which justify, or otherwise, necessary costs. The total procedure takes approximately five to 10 minutes.

Identified benefits for a large grass-roots project, implemented in an existing site

After having completed an ergonomics programme as mentioned above on a $400 billion investment, the costs and benefits have been analysed together with the future operations and maintenance organisation, own project management, and the engineering contractor involved in basic engineering, detailed engineering, procurement and construction.

Although in such an exercise costs and benefits are sometimes partly intangible, many tangible costs and benefits have been identified. Although the contents of the complete report cannot be disclosed in this article, it can be mentioned that during engineering approximately 150 man days were used for analysis and engineering follow-up and approximately one man year for follow-up during construction. Minor costs, eg for making CD-ROM with animated training material for construction firms, are not included.

The "Look Back" exercise/analysis showed :

—Identified Capex saving were in the order of $2 million or 0.25 per cent of capital (it is believed that this figure is higher due to material wastes resulting from construction REDO

—Additional Capex was estimated to be $60 000, to improve operations and maintenance

—Identified savings during the first 10 years of operation amounted to $0.9 million

—Identified cost savings during two four annual major shutdowns were estimated to be $460 000

—A large list of intangible benefits, related to safety, health and environment. [FEEEM analysis report MSPO/2, ABB Lummus, Netherlands].

Integration of human factors

Figure 5 shows in more detail the procedure by which ergonomics has been be integrated in a single object oriented, database-driven CAE systems.

The CAE system, CC Plant based on the CATIA kernel of object oriented design and engineering, has the availability to capture design intent and apply Knowledge Based Engineering (KBE). During a recent project, using these advanced, fully Product Data Model-based, techniques, a plant was designed and engineered with the human factors engineering discipline participating with other disciplines, as explained below.

The participation of ergonomics began with the given area for the plant to be built, because this will put the spatial constraints on the table. Given typical areas for known plants and technologies normally used are not at stake, because experience with the ergonomic analysis shows that this will not lead to the need for a greater area.

In the case of the particular project to be built at an existing plot after demolition of a former plant, the residual existing buildings had to be taken into account, and to be used if needed (such as substations, field auxiliary

X

rooms, analyser houses, etc). In figure 5 it can be seen that on the basis of the PFD an initial 3D block model was made very early during the feasibility phase. With fully integrated intelligent 2D/3D engineering (one single database) this effort is negligible.

The procedure shows how this preliminary block model, after it had served to save some 2 to 3 per cent on capital investment during the process optimalisation, is used to define further refinements. On the basis of the analysis based on the FEEEM, demands are defined as to equipment on the one hand and detailed operating and maintenance (life-cycle) philosophies on the other.

It can be seen from the figure that the design analysis is done in a concurrent mode with the development of the PEFDs and that some constraint handling between ergonomic, operational, maintenance and engineering demands is already taking place.

With respect to spatial equipment design, which at the same time is developed as well, the ergonomic analysis leads to demands on free areas needed around equipment and these design intents are defined as part of the equipment in the equipment catalogue. With respect to the operating and maintenance philosophies, the ergonomic analysis yields spatial demands in terms of soft boxes (a technique also used in conventional 3D systems, but at a much later stage in this project). This is based on identified needs for lay-down areas for inspection and maintenance, operator rounds, emergency routes, logical safety shower positions, hoisting and transport needs.

Looking at the initial preliminary and very simple block model, one can see that this gave the design team a second use, for piping transpositions and layout optimalisation studies.

The operating and maintenance demands, the optimal piping layout and other mostly common engineering or statutory layout demands are all combined and used to arrive at the final constraint analysis necessary to define the plant's civil building, including the often *combined* soft boxes necessary for optimal piping, ergonomics or statutory demands.

Only when the building, with all its soft boxes, is defined is it time to place the equipment finalised in the equipment catalogue. It is obvious that this exercise, as simply explained here, is not a straight or "from start to finish" exercise, but that a number of recycles, as a result of work in progress, exist to make further optimalisations. Although the sceptical may doubt the efficiency of the procedure, it can be said that, because the approach is very structural and professional, considerable time is saved, not only during the procedure itself by avoiding many conventional and "out of sync" recyles, but especially by avoiding a lot of recycles during the later detailed engineering.

It should be remembered that apart from the defined ergonomic demands on equipment and general layout as used in the above procedure, the FEEEM analysis also generated many demands for the detailed engineering phase on piping, instrumentation and so-called field run items (small bore, secondary cable tray, lighting fixtures, etc).

Ergonomic analysis (as well as other types of analysis) and the use of a data centric object orientated single database can be considered synergetic.

Martin E J van Uden is a coordinating process engineer with Shell International Chemicals, Amsterdam, The Netherlands.
Harrie J T Rensink is group adviser, human factors engineering, with Shell International, at The Hague.