Return on investment by the use of human factors in systems design.
Part 2
The implementation of a human factors engineering strategy in petrochemical engineering and projects

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1.0 INTRODUCTION

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 has 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".
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 - 5 % of capital expenditure (CAPEX),
- 1 - 10 % of the total engineering hours and
- 3 - 6 % of operational and maintenance life-cycle costs of facilities (OPEX).

This paper consists of two parts. Part 1 describes 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 will give the reader insight in the actual Project Management and Quality Assurance of Human Factors Engineering in petrochemical projects.

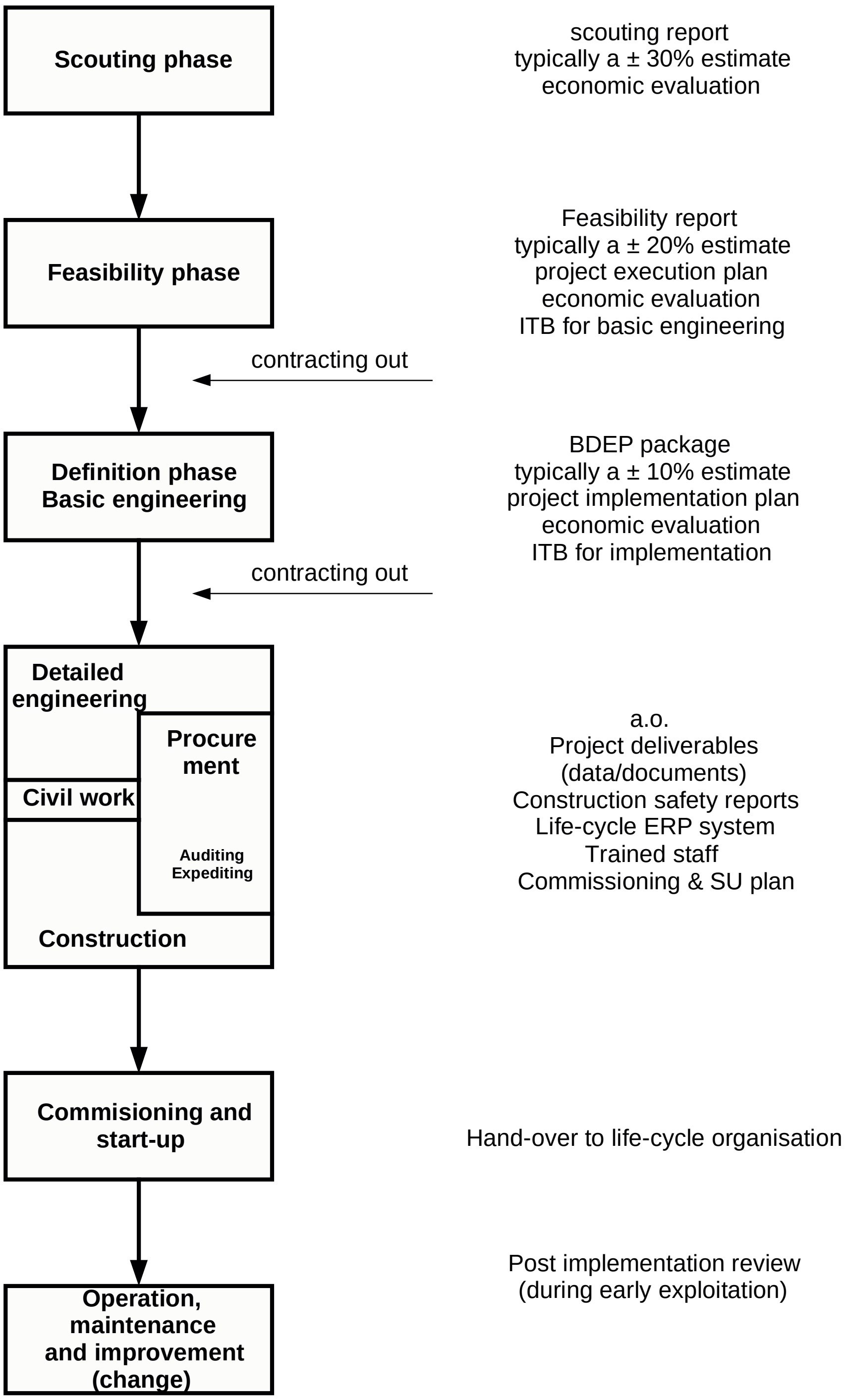
The above explained statements that human factors and ergonomic principles are not sufficiently anchored in the design process is not world shocking. However, especially for projects in the petrochemical industry, a clear recipe cannot been found in literature. Much wise words have been written but an incorporated control system is not found.
In chapter 2 the project business process is analysed. It will be discussed where and how ergonomic principles should be integrated in the process. Chapter 3 will further give the total frame work in terms of a warranted quality system, including management monitoring tools and system auditing.
In chapter 4 the main driver for integrating human factors in the technical design process is discussed, being the benefits of integrating ergonomic principles in the business process. One could discuss to deal with costs and benefits in the first place as well, but in this article we have chosen not too, as the cost/benefits are probably better understood after reading about the management system and underlying tools.
In chapter 5 an example of integration of Human Factors Engineering into new engineering developments will be given.

2.0 THE TRADITIONAL '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 basis of existing, improved or new technology (ies). 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 ± 10%). At this point business premises and forecasts are frozen and an economic evaluation,

FIGURE 1

Typical high level business process description "PROJECT PREPARATION AND EXECUTION"



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% 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 completely described in requisitions, being the starting point for the procurement.
During detailed engineering drawings (or now-a-days drawings based on data) are produced to enable the constructors to build the petrochemical facility. During the last decades (two dimensional) computer techniques have been increasingly used and during the last decade graphic oriented 3D computer imaging has been used, while today 2D and 3D design is integrated on basis of object oriented design and engineering. Today virtual reality is commonly used on the construction side as well after construction the new facility is tested and started-up.
The process as described above can be shown in relation with time schematically, showing the deliverables of each process step on the right hand, as shown in figure 1.

2.2 The input of engineering disciplines in the design process

During the process of design, engineering, procurement and construction many engineering disciplines are involved, e.g. process technologists/engineers, mechanical, electrical, civil and instrumentation engineers. Cultural, strategic, and logistic considerations give a continuous input during the design process, resulting in decision 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 de-bottlenecking 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 managers role, we have noticed and are of the opinion that the system (organisation and availability of the correct procedures and behaving culture) in which the responsible project manager has to work is of determining influence to the success.
Budget constraints (foreseen or unexpected) are a danger for good integration between the disciplines as this is often thought or at least it is easy to think that this is in conflict with proper engineering, procurement and construction.
It should be noticed 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 some "punishment" for this policy is received as well.
Engineering contractors "unfortunately" do not operate the plant and are therefore not obtaining enough feedback (as a company engineer will) to improve the level of his engineering skills with respect to anticipating life-cycle operations, maintenance and other risks. Therefore and further greatly depending on the type of the contract, EC's are not always too interested in the plant life after construction has finished.

The above constraints definitely influence the quality of the projects.

2.3 Lack of user participation in design

Those who have read the previous paragraphs may have noticed that some important participants in the project have not been mentioned yet. This important group of, let us say "potential" contributors to the design, are often NOT, TOO LATE or in only an informal COMMENTING WAY involved during the design process. They are those 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 to 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 full fills the "basis of design" and concentrate themselves on those issues but that the end-users are motivated to operate and maintain the plant in an efficient and effective way and are more concentrated towards the life-cycle. Although engineers told and apparently thought that they had sufficient empathy for the life-cycle, more detailed questioning brought them into the situation in which they concluded and confessed they were not enough taking the life-cycle of the plant under design into consideration. The attitude of the engineer can be generally explained as an attitude in the sense of : “......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 claimed that this increases exploitation costs.
The fact is that if end-users, as being 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 availability of operational and maintenance staff during the design and methods should therefore be developed to overcome this dilemma efficient.

2.4 Problem definition

Ergonomics or human factors engineering is "easily forgotten" during all phases of a project (Refer to Part 1 of this article for the arguments leading to this statement).
This leads to many disadvantages, amongst others extra costs during the 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 assure the knowledge of ergonomics, human factors engineering, task analysis of which the results have influence on the design and user participation.

2.5 Conclusion of the above analysis

Too many ergonomic misfits exist in petrochemical plants, even those recently built even after already 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 only be best achieved by an ergonomic awareness program for all those involved in projects, through organisation and management procedures and last but not least by showing the economical and non-economical benefits of human factors engineering in projects. Furthermore the application of new simulation tools based on data centric and object oriented, and thus 2D/3D integrated (dynamic) engineering systems, with a proven history in the automobile, aircraft and shipbuilding sectors of the industry, will lead to extremely simple and early 3D simulation of the plant under design. This leads to better understanding an early "design out" of ergonomic misfits as well as optimised life-cycle oriented designs.

3.0 MANAGEMENT OF HUMAN FACTORS ENGINEERING IN PROJECTS; THE PROCEDURE TO FOLLOW

3.1 Introduction

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 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 can be noticed that already early in the design ergonomic demands have to be specified; the main reasons being :

- that it is in this phase that inside battery limit (IBL) operational and maintenance philosophies are being defined
- that the design is still flexible in its scope definition, so that ergonomic demands, especially on IBL philosophy level can be 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 as given in the centre part of figure 2 can be followed to understand the scope, purpose, organisation and management of human factors engineering in projects. Keywords in this procedure are : Plant lay-out, 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 costs savings and occupational health and safety benefits. In doing so, the design will also reflect the way the future operators and maintenance people of the system want to utilise their system effectively while at the same time they understand and accept that impossible demands in view of additional investment versus low benefits, are not implemented. The procedure in general leads to lower Capital expenditure (CAPEX) as well as lower life cycle costs of installations and costs of plant change (ref. 1).

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 proceeding phases.

This procedure is applicable for new grass roots projects as well as for brown fielders and de-bottlenecking or major retrofitting. The procedure demands the co-operation 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 <u>need</u> the input of life-cycle users <u>in time</u> to avoid later changes during detailed engineering or even worse during construction, not to speak about changes during the life-cycle as such.

Below the key steps of the the procedure are discussed; 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.

Identify necessary human factors engineering input with respect to the project scope

The person responsible for putting together the Basic Process Design Package (BDP or often called BOD) and/or the Basic Design and Engineering Package (BDEP), often the process engineer or the project co-ordinator/manager, should discuss and evaluate with the human factors engineer, the necessary effort for the project. Within our Company protocols and checklists for facilitating this discussion are available.

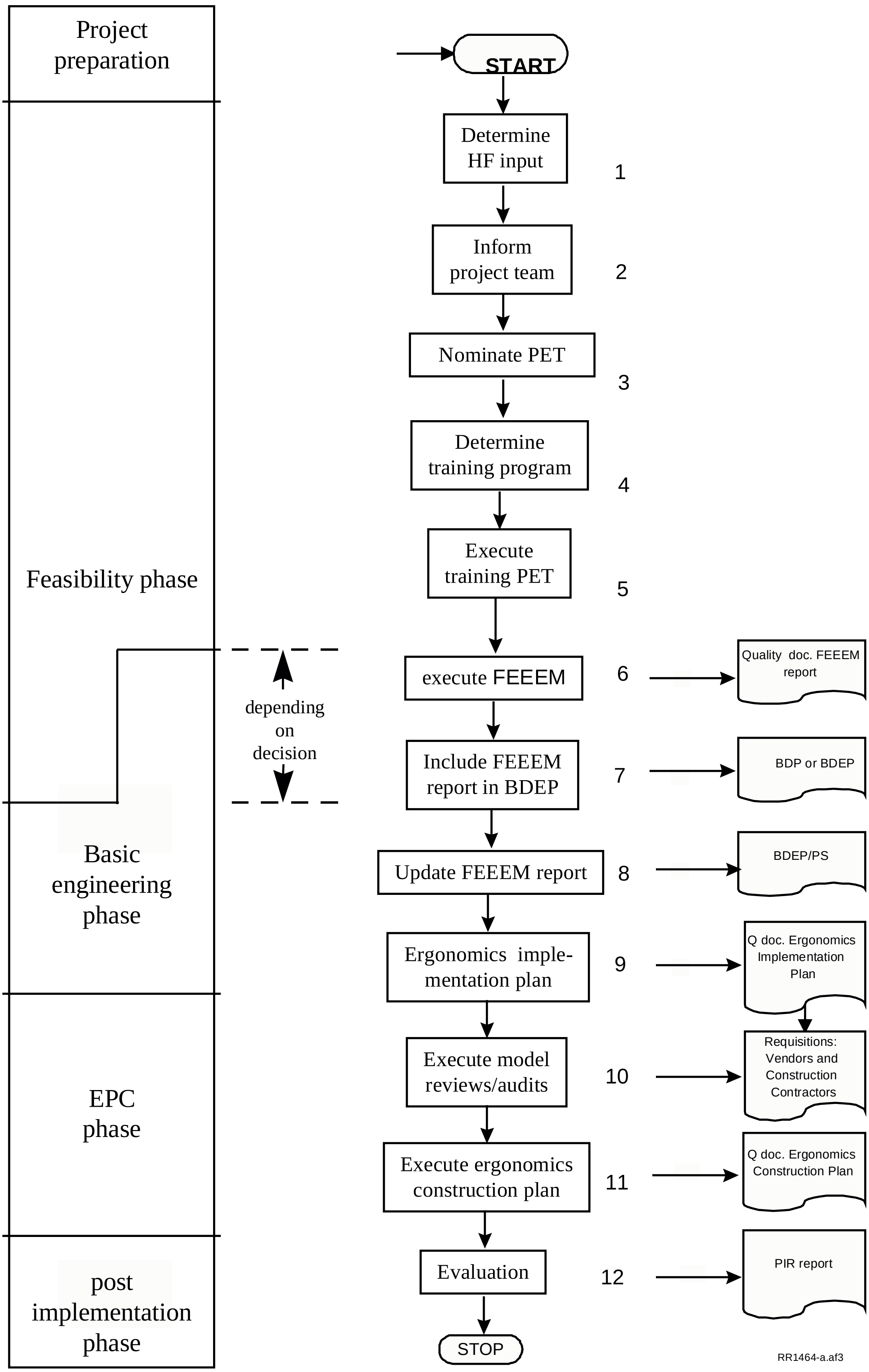
Inform project team/manager/Kick off meeting

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 captured later, although many times the challenge from the project team leader indicated differently. The agreed Human Factors Engineering plan of action is then part of the agenda of the project kick-off meeting. Within larger projects (> $ 50 million) the human factors engineer often plays a co-ordinating role

Nominate the Project Ergonomics Team (PET)

The person responsible for drafting the BDP and/or BDEP should nominate (in consultancy 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 and the human factors engineer.

FIGURE 2


Project preparation
Feasibility phase
Basic engineering phase
EPC phase
post implementation phase
depending on decision
START
Determine HF input
1
Inform project team
2
Nominate PET
3
Determine training program
4
Execute training PET
5
execute FEEEM
6
Quality doc. FEEEM report
Include FEEEM report in BDEP
7
BDP or BDEP
Update FEEEM report
8
BDEP/PS
Ergonomics imple-mentation plan
9
Q doc. Ergonomics Implementation Plan
Execute model reviews/audits
10
Requisitions: Vendors and Construction Contractors
Execute ergonomics construction plan
11
Q doc. Ergonomics Construction Plan
Evaluation
12
PIR report
STOP
RR1464-a.af3

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 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 (ref. 2, 3)

Process engineer/discipline engineer and project manager should have participated in a full scope human factors competence improvement training, focussing on costs/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 thought relevant.The human factors engineer will co-ordinate the execution of the training requirements as specified in this step of the procedure. Normal training is ranging from 4 to 8 hours.

Execute FEEEM ® design analysis

This analysis should be implemented by the PET according to the procedure. The Frond End Ergonomic Evaluation Matrix design analysis describes a multi-disciplinary task analysis method to be apply during feasibility or definition phase to evaluate potential ergonomic bottlenecks in the design. This procedure is part of the Pernis Projects Quality system (ref. 4). The FEEEM ® procedure is shown in Appendix 1. A standard part of the FEEEM® design analysis is implementation of the Identification of Valves Analysis (IVA®) (ref. 5). The results of the FEEEM® 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 (ref.6). In 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 like e.g. link analysis methods aiming at an efficient control room building lay-out for human efficiency improvement during normal and emergency operations.

Include the FEEEM report in the BDP or BDEP/PS document

The person responsible for co-ordinating 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 up-dated and the resultant actions derived by the FEEEM® report should be verified in relation to the scope of the BDEP/PS and integrated into the initial plot plan. Assure FEEEM® analysis results, for instance identified 'soft boxes' of critical maintenance or logistic routing are integrated in the lay-out of plant.

Determine Ergonomics Implementation Plan

End of BDEP/PS phase the Ergonomics Implementation Plan is set up to secure the ergonomic requirements and demands, resulting from the FEEEM analysis, during detail engineering, procurement and the construction phase. For projects less than $ 5 million CAPEX, it is in general sufficient to include the FEEEM® report into the Project Execution Plan/Project Implementation Plan. The project manager should be committed to and 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% of the detailed engineering phase (see chapter 5 for special integration of ergonomic analysis with state of the art 2D/3D integrated CAE systems). 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. Often the life-time proves that impressive constructed procedures do not work in the life-cycle and have to be violated through safety and health risks and costs; dynamic functional simulation, now-a-days becoming available, will be more and more used. Special attention should be given to Skid packaged units.

Execute the Ergonomic Construction Plan

This plan's purpose is to guide the construction contractor about installing "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 etc. The plan normally includes :

- inserting ergonomic requirements into standard paragraphs of contracts with installation contractors, including procedures how to handle diagnosed misfits
- awareness sessions with on site contractors.
- use physical (3D) model on site for reference
- execution of "ergonomic verification rounds".

Evaluate the application of human factors engineering

The human factors engineer, the project manager and/or client's maintenance manager normally will decide to evaluate the successes or failures of the ergonomics program during the post-implementation period.

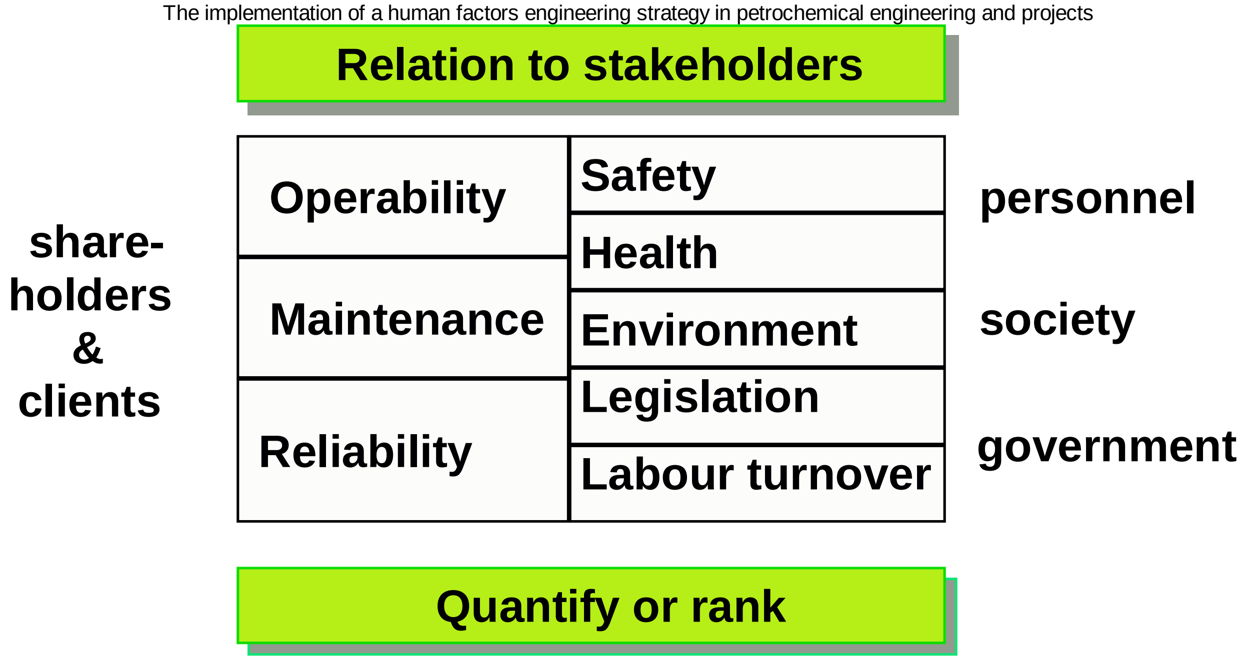
4.0 COST AND BENEFITS

Showing costs and benefits of programs normally motivate professionals to apply or not apply programs. To demonstrate the benefits of the implementation with respect to costs an extensive study was done into the cost and benefits items by Shell Nederland Raffinaderij and Shell Nederland Chemie in Pernis and Moerdijk, in cooperation with Nederlandse Aardolie Maatschappy Assen some three to four years ago (ref.7).
Generally it was found that benefit/cost ratio for new (grass roots or brown field projects) are high, but that also in de-bottlenecking 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 directly paid out of the exploitation budget, which were meant to abandon ergonomic misfits existing in plants in operation. Justification of such investments was often done on rather soft grounds, based on a kind of common sense and understanding rather than backed by economic or other calculations. It was there were the study team concentrated themselves. It was believed that a model able to discriminate between the justification of these type of exploitation costs or not, could certainly also be used for the larger grass roots or brown field projects.

4.1 **Benefit area's**

As costs can normally be estimated up front on basis of scope and hours, the team first concentrated on the benefit areas; three levels of benefit areas were established. The high level of benefit areas were defined at stakeholder level, where a rough definition of a stakeholder is that this is anyone or any group sharing the costs and other disadvantages and/or the benefits and other advantages of the business.
In figure 3 below a graphic representation is given of the high level benefit area's in relation to the main stakeholders.

FIGURE 3



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 below in figure 4, is an example how benefits are ranked. A third level of benefits are long checklist, belonging to each of the second level benefits on the left hand side of figure 4. This third level of benefits are of great help to identify benefits, which are then classified in the matrix shown below.

FIGURE 4

no.	Description of benefit	operations	maintenance	reliability	safety	health	environment	legislation	labour turnover
1	Saving time/human resources	X	X						
2	Saving product	X							
3	Waste reduction	X	X				X		
4	Reducing/preventing errors	X	X	X	X	X	X		
5	Reducing/eliminating physical/mental stress	X	X			X			
6	Reducing training costs (requirements/time)	X	X						
7	Improving the quality of the end-product	X							
8	Preventing damage/risk to plant	X	X	X					
9	Making operators' inspection rounds more effective	X							
10	Improving maintenance quality/life-cycle extension	X	X	X					
11	Parts savings		X						
12	Saving on hoisting/transport costs	X	X						
13	Saving on tools	X	X						
14	Saving on dirty work/cleaning/PPE costs	X	X		X	X			
15	Saving on workshop costs		X						
16	Saving on scaffolding costs	X	X		X				
17	Reducing the risk of trips	X		X	X				
18	Preventing/shortening plant shut-downs	X		X					
19	Preventing temporary capacity reductions	X		X					
20	Savings on monitoring on job-related risks					X			
21	Reducing unauthorised overrides of protective systems	X		X	X				
22	Increasing process safety	X			X				
23	Increasing operational safety	X			X				
24	Fewer control measures required	X	X		X	X	X		
25	Reducing the risk of accidents				X				
26	Preventing health-related absenteeism					X			
27	Reducing occupational diseases					X		X	
28	Preventing compensation claims and related internal discussions				X	X	X	X	
29	Reducing the number of employees who become unfit for work					X			X
30	Reducing the number of days of adapted work					X			
31	Preventing impaired performance					X			
32	Improved occupational hygiene (toxicity, noise, etc.)					X			
33	Reduced pollution of the soil/water/atmosphere						X		
34	Reducing the probability of environmental incidents						X		
35	Reducing the number of environmental complaints						X		
36	Improving the company's image/reputation	X			X	X	X		X
37	Preventing/reducing notices/sanctions from the HSE authorities							X	
38	Improving the staff motivation								X
39	Reducing the number of vacancies which are hard to fill								X
40	Improving the performance of older/sick personnel					X			X
41	Reducing demurrage	X							

After the identification of the benefits, the benefits need to be quantified. If the identified benefits are to a great extent feasible to be estimated, the benefits are outweighed against the estimated costs. In many cases however the benefits are rather intangible, e.g. "What is the $ value of safety ? ".
In cases where no tangible figures can be derived from the benefits, the benefits are simply ranked according 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 on basis of the exposure class and effect level.

4.3 **Costs and ranked or quantified benefits**

As mentioned above benefits with a tangible content may already simply 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 pay-out criteria, which have been agreed before with management. So for intangible benefits, only the benefit with the highest classification counts, while for tangible benefits benefits ($) can be added. The pay-out criteria just mentioned are also dependent of the height of the costs. If pay-out criteria are reduced to zero a full intangible benefit has justified the costs to be made. In most cases there is a combination of intangible and tangible benefits, which justify or not justify necessary costs. The total procedure takes approximately 5 to 10 minutes.

The tables and matrixes as discussed in 4.2 and 4.3 have not been further shown as the application and threshold levels are fully dependent on Company policy.

4.4 **Identified benefits for a large grass root project, implemented in an existing site.**

After having completed an ergonomics program as mentioned above on an $ 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 can not 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, e.g. for making CD-ROM with animated training material for construction firms, are not included.

The "LOOK BACK" exercise/analysis showed (ref.8) :

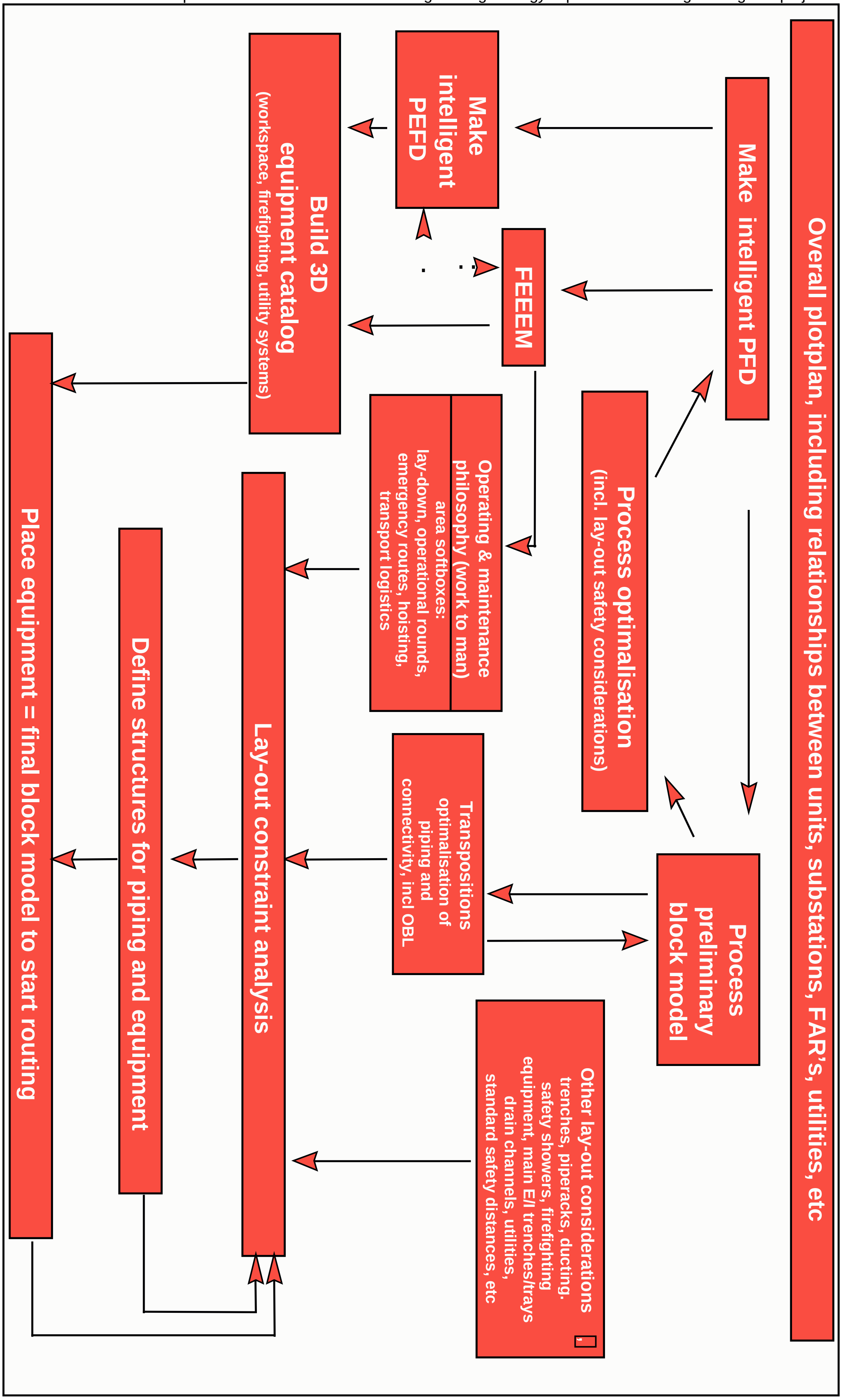
- Identified CAPEX saving were in the order of $ 2 million or 0,25 % of capital (it is believed that this figure is higher due to material wastes resulting from construction REDO.
- Additional CAPEX was estimated to be $ 60,000.- to improve operations and maintenance
- Identified savings during the first ten 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.

5.0 **INTEGRATION OF HUMAN FACTORS ENGINEERING INTO NEW ENGINERING DEVELOPMENTS**

In figure 5 the procedure is shown in more detail how ergonomics has been be integrated in a single object oriented database driven CAE system with integrated and thus consistent functional and physical design and engineering capabilities. 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 and the Human Factors Engineering Discipline was participating in a true concurrent mode with other disciplines as explained below.
The participation of ergonomics all started with the given area for the plant to be built, because this will put the spatial constraints on the table. It can be mentioned at this stage that given typical areas for known

plants and technologies normally used are not at stake, because experience with the ergonomic analysis shows that this will certainly not lead to the need for more area.

FIGURE 5


Overall plotplan, including relationships between units, substations, FAR's, utilities, etc
Make intelligent PFD
Make intelligent PEFD
FEEEM
Build 3D equipment catalog
(workspace, firefighting, utility systems)
Process optimalisation
(incl. lay-out safety considerations)
Operating & maintenance philosophy (work to man)
area softboxes:
lay-down, operational rounds, emergency routes, hoisting, transport logistics
Process preliminary block model
Transpositions optimalisation of piping and connectivity, incl OBL
Other lay-out considerations
trenches, piperacks, ducting, safety showers, firefighting equipment, main E/I trenches/trays drain channels, utilities, standard safety distances, etc
Lay-out constraint analysis
Define structures for piping and equipment
Place equipment = final block model to start routing

In the case of the particular project to be built at an existing plot after demolishment of a former plant, the existing residual existing buildings, etc had to be taken into account and to be used if needed and attractive (e.g. substations, field auxiliary rooms, analyser houses, etc.). In figure 5 it can be seen that on basis of the PFD an initial 3D block model was made very early during the feasibility phase as discussed before. 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 % on capital investment during the process optimalisation, is used to define further refinements. On basis of the analysis based on the FEEEM matrix, demands are being defined to equipment on the one hand and detailed operating and maintenance (life-cycle) philosophies on the other hand. It can be noticed from the figure that the FEEEM ® design analysis is done in a concurrent mode with the development of the PEFD's and that some constraint handling between ergonomic, operational, maintenance and engineering demands is already taking place at that moment. In fact at the right moment, thereby excluding a number of engineering recycles or even worse….ending with a less optimal design.

With respect to spatial equipment design, which at the same time (concurrently) 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 catalog. With respect to the operating and maintenance philosophies the ergonomic analysis yield spatial demands in terms of soft boxes (a technique also used in conventional 3D systems, however at a much later stage in this project), 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 at least served the design team a second time by using it for piping transpositions and lay-out optimalisation studies.

The operating and maintenance demands, the optimal piping lay-out and other mostly common engineering or statutory lay-out 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 it is time to place the equipment finalised in the equipment catalogue. It is obvious of course that this exercise, as simply explained above, 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 suspicious reader may doubt the efficiency of the procedure it can be said that, due to the fact that the approach is very structured and professional, considerable time is saved, not only during the procedure itself, by avoiding many conventional and 'out of sync' recycles, but especially by avoiding a lot of recycles during the later detailed engineering. It should be mentioned that apart from the defined ergonomic demands on equipment and general lay-out as used in the above procedure, the FEEEM ® analysis also generated many detailed demands for the detailed engineering phase on piping, instrumentation and so-called ' field run' (e.g. small bore, secondary cable tray, lighting fixtures, ect.) items. Ergonomic analysis (as well as other types of analysis) and the use of a data centric object oriented single database can be considered synergetic.

References:

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APPENDIX 1 FRONT END ERGONOMIC EVALUATION MATRIX (FEEEM®)