The Feasibility of Encouraging Inherently Safer Production in Industrial Firms

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Summary

Inherent Safety is generally recognised as an important concept in the design of chemical plants. It is, however, often regarded as the sole province of engineers. Inspired by the successful development in the last decade from cleaner technology towards *cleaner production,* we explored in this research the feasibility of what we call *Inherently Safer Production*. Four pilot cases were carried out, two in the Netherlands and two in Greece; three in existing plants, one at the design stage. A methodology to generate inherently safer technological options was developed and tested. In all four cases, a number of options for inherently safer production were identified, while more traditional safety options were also identified. The great majority of options was shown to have pay back times of less than two years. Overall, twenty-five percent of the options were implemented during the project.

In existing plants, the option generation process can be organised as a collective learning and inspiring effort. This can be of considerable value on its own, apart from the implementation of the (technological) options identified. We conclude that *inherently safer production* is a feasible concept, that it has great potential for simultaneous improvement of safety and economic performance, and that it deserves to be further developed.

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Introduction

The Concept of Inherent Safety

Most chemical production involves "transformation" processes, which are inherently complex and tightly coupled. "Normal accidents" are an unavoidable risk of systems with these characteristics (Perrow 1984). In many cases, alternative chemical processes exist which completely or almost completely eliminate the use of highly toxic, volatile, or flammable chemicals. Accidents that do arise in these systems result in significantly less harmful chemical reactions or releases.

The concept of inherent safety, originally developed by Kletz (1978), is now well known among chemical engineers as sound principles for the design of new facilities, and it is developed into a vital part of the curricula of engineering schools in several parts of the world (Hendershot 1993, Lutz 1995, IchemE 1995). However, we feel this concept can also be used in existing facilities (Zwetsloot 1998), and the use of the concept is still too limited, because it is seen as only an engineering function and because of both conceptual and institutional barriers for the adoption of Inherently Safer Technologies (Kletz 1990, 1998, van Steen 1996).

The basic design principles to generate Inherently Safer Processes can be clustered in several ways (Bollinger et al 1996, IChemE 1995, Kletz 1990 and 1998). We adopt the four categories used by CCPS (Bollinger et al 1996): Minimise, Substitute, Moderate, and Simplify, but we add the principle of *optimal plant lay-out* because we feel it is essential for the inherent safety of logistical activities.

Our inspiration from Cleaner Production Approaches

Replacement of existing production systems by benign chemical processes, as well as non-chemical approaches, has historically focused on pollution prevention or cleaner production. Here, we feel a need to expand the focus to inherent safety. The terms "Cleaner Production" and "Pollution Prevention", not only address technological aspects but also organisational and human factors (Baas et al 1990, Ashford, 1994). In an analogous fashion, we adopt in this project the similar term ***Inherently Safer Production*.**

The breakthrough towards Cleaner Production was generated by a series of demonstration projects that showed that such projects can generate many economically feasible opportunities for cleaner production in existing companies (e.g. de Hoo 1991, see Van Berkel 1996 for an overview). Today, many countries have programmes to promote cleaner production (e.g. the EU LIFE programme), both at the design stage and in existing companies. As of 16 November 2000, the International Declaration on Cleaner Production[2] (UNEP 1999) was signed by 42 national governments from all continents, by 61 companies and many other high level organisations (UNEP 2000). The International Standard for Environmental Management, ISO 14001, contains explicit requirements for pollution prevention; as of January 2001 more than 17,000 companies are certified for ISO 14001, and thus have at least partly integrated pollution prevention principles into their environmental management systems.

[2] The global declaration on Cleaner Production states: "we understand Cleaner Production to be the continuous application of an integrated preventive strategy applied to all processes, products and services in pursuit of economic, social, health, safety and environmental benefits" (UNEP 1999).

We mused why similar developments have not taken place with respect to safety. We regard *inherent safety* as a concept similar to – or a natural extension of -- pollution prevention or cleaner production. Both attempt to prevent the possibility of harm -- from accidents or pollution -- by eliminating the problem at its source. Both typically involve fundamental changes in production technology: substitution of inputs, process redesign and re-engineering, and / or final product reformulation.
This raises questions such as: can similar approaches as used in CP programmes lead to the identification of inherently safer technological options to improve safety? Are such options economically attractive? We undertook a feasibility study to throw light on these questions.

The purpose of this research

This research project was designed to gain practical, firm-based experience regarding the feasibility of an approach to partner firms with technically-informed and inherent safety oriented consultants. The central research questions in this study were: (1) Does the approach lead to the identification of inherently safer (technological) and economically feasible options? (2) What were the strengths and weaknesses of the approach? (3) Are demonstration projects for the promotion of inherently safer production feasible?

Materials and methods

Our methodology was developed as a safety analogue of the methodologies in Cleaner Production demonstration projects [see e.g. de Hoo et al (1991), p 62-72], and our knowledge of inherent safety principles. The underlying concept was to encourage firms to exploit the opportunity to prevent accidents and accidental releases (1) by identifying *where* in the production process changes to inherently safer inputs, processes, final products and equipment could be made and (2) by identifying the specific inherently safer technologies that could be used. The former we call Inherent Safety Opportunity Audits (ISOAs). The latter we call Technology Options Analysis (TOAs). Unlike a hazard, risk, or technology assessment, these techniques seek to identify where and what inherently safer technologies *could be adopted, or in some cases developed*.

Our approach consists of three phases, each comprising several steps or activities, and the use of some specific tools. As it was not our intention to prove the value of a blueprint methodology, but rather to develop a methodology that makes a change towards inherently safer production possible while meeting the needs of industry, the approach was open to change according to the needs of the respective pilot companies. Two phases were added for evaluation purposes. The phases are concisely described below; a full description of the initial approach has been published elsewhere (Ashford & Zwetsloot 1997).

We call phase one, *Preparatory work &, obtaining firm commitment.* This stage consists of the following steps: (1) Start-up and obtaining commitment from the firm, (2) Initial design and preparation, (3) Conduct of a traditional safety audit, and (4) Selection of candidate processes or operations within the firm. Stage two is focused on *Identifying Inherently Safer Options*. It consists of the following steps: (1) Carrying out a functional review, (2) Developing a specific set of search questions, (3) Brainstorming to generate inherently safer options, (4) Constructing a search process for information on inherently safer options/alternatives, (5) Identifying promising inherently safer options, (6) Designing a consistent set of system changes, (7) Carrying out a feasibility study, (8) Getting commitment of the project team, and (9) Giving recommendations to management. The possibility of introducing new hazards (by the adoption of an alternative technology) was explicitly considered and evaluated in step 6. This was based on the extensive experiences in safety, industrial hygiene and operations of the two research teams. Stage three aims at *Implementation* and consists of three steps: (1) Facilitating decision making, (2) Preparation of implementation and (3) Actual implementation.

The two additional stages (only for research purposes) are: *Monitoring & evaluating implementation* (monitoring actual design changes and progress in implementation) and *Evaluation of the case.*

In the approach described above, there are several links with traditional safety management. This is most prominent in the steps to achieve management commitment (phase 1 and 2), the use of a safety audit (phase 1), taking into account economic considerations (phase 2) and activities to facilitate decision-making and implementation (phase 3).
We used a broad definition of inherent safety, comprising the hazards relevant for: Process Safety (fire, explosion, runaway reaction, etc.), Occupational Safety, Environmental Safety, Product Safety, Acute Effects on Occupational Health, Acute Effects on Community Health or Nuisance, and all kinds of sudden and accidental releases.

The case studies

Partner firms were engaged to explore the usefulness of the approach in case studies. Considerable effort was required to convince companies to co-operate. Two partnerships were created in the Netherlands, one with Hoogovens Steel Strip mill Products (HSSP, today part of Corus) for a pilot in their Hydrochloric Acid Regeneration plant, and the other with DSM, the Logistics department of the Hydro Carbon Unit. In Greece, a partnership was created with ELAIS (Editable Fats and Oils, part of the Unilever group) for two pilots, one focusing on its present installations in Athens and the other involving the design of a new plant for refining editable oils. Researchers from TNO carried out the pilots in the Netherlands, while the pilots in Greece were carried out by researchers from Ergonomia Ltd. The pilots were carried out in the period 1997-98. In this article, only concise summaries of the case studies are given. The full case studies are published in Zwetsloot & Askounes-Ashford (1999, p 64-120) and were verified by the responsible contact person of the respective firms. The findings in the cases regarding the impact of the methodology on the *willingness* and the *capability* of the firms to adopt an inherent safety approach are presented in more detail in Ashford & Zwetsloot (2000).

Concise descriptions of the individual case studies

Case 1: Hydrochloric Acid Regeneration at Hoogovens Steel Strip mill Products (HSSP)

Hoogovens Steel Strip mill Products (HSSP) is a business unit of Hoogovens Staal BV in IJmuiden, the biggest steel company in the Netherlands (recently part of the UK-Dutch company Corus). One of its factories is Cold Strip Mill II where sheets of steel are produced. These sheets are treated (pickled) with hydrochloric acid. The Regeneration Plant was built in 1972 to regenerate the hydrochloric acid. The plant is situated on the Northern part of the huge industrial site of Hoogovens, next to the North Sea coast and near the city of Beverwijk.

The Regeneration Plant is an open, four story high metal construction following the basic concept of the firm Ruthner. The original process was up scaled to achieve the desired capacity. In the first years the only product was the regenerated hydrochloric acid; later, there appeared to be a market for the by-product Ferrous Oxide. Before the project started, there were many problems with process control resulting in a lot of trouble shooting activities. Internal pollution of the facilities was a structural problem, reliability of production was below the targets, there were several hazardous situations (especially during trouble shooting), there were too much sudden emissions to the environment (e.g. Ferrous Oxide dust or a mist of Hydrochloric acid), and the Ferrous Oxide was not always of the best quality (contaminants). The plant's safety, health, and environmental data were unfavourable. Despite efforts of the maintenance department and the plant personnel itself, and the temporary appointment of an extra officer to boost progress, there was little improvement. This was the main reason for participation in the project.

Adaptations in the approach

Instead of the traditional safety audit, a more specific Inherent Safety Opportunity Assessment was developed and carried out. In the second phase, a multi-disciplinary workshop was organised with engineers, operators, maintenance staff, and safety officers from Hoogovens. Using these sources of in-company know-how the problems assessed were analysed, and options for solutions were generated in a brainstorming session. Instead of an external data search, an external TNO expert in regeneration of hydrochloric acid was involved in the generation of options and selection of the cases.

Options Identified

After the workshop, a choice was made for a package of promising options that could lead to a consistent set of improvement measures. The criterion that the measures should lead to Inherently Safer Production was used less stringently in this phase; the main objective was to address the most urgent safety or operation problems in the existing plant. For each of the options a rough cost-benefit analysis was made. Health and Safety benefits were taken into account, using the system HSSP normally uses for this purpose. Except the substitution of the chemical process it-self, all other options had payback times less than 1 or 2 years, and were considered feasible. On the basis of this analysis, the manager maintenance department approved eight of the nine project plans. An overview of the options identified, their economic feasibility, their adoption and the progress twelve months after identification of the options is given in table 1.

Table 1 about here.

Evaluation of the case

During the case, there has been a remarkable improvement in the safety and environmental performance of the Regeneration Plant realised during this year, this is shown in table 2.

Table 2 about here.

Notably, 13 of the 14 environmental incidents in 1997 happened in the first half of the year, before the personnel of the plant was involved in the project. The problems with regards to the quality of the Fe_2O_3 that the plant struggled with last year are over. The only type of disturbance of the process that still is occurring as frequently as in 1996 and 1997 is the leaking of the lances (8 to 12 times per year). There have been no more broken rubber tubes (the most dangerous situation) in 1998. Remarkably, the greatest progress was realised *before* the identified options were implemented. For the plant's personnel and managers there was no doubt: the first two phases of the methodology had been extremely helpful to better understand the process control and related safety problems. It had helped them to set clear priorities in maintenance and to guide investments for incremental technological improvements. Without further help of the researchers, they adapted several steps from the first phases of our methodology and used them to better understand other process control, environmental and quality problems -and with success. For the researchers, the successes in these early stages were unexpected. It indicates that the first two phases of our methodology can be used as a tool for safety management, and can have considerable value on their own, apart from the implementation of the (technological) options identified.

Case 2: Logistics Department at Hydro Carbon Unit from DSM.

DSM is a multinational chemical company, with its headquarters in the Southern part of the Netherlands. The division DSM Hydro Carbons (DHC) is a business unit of DSM Limburg BV in Geleen. One of its departments is Logistics. DHC is operating in a five shifts scheme with in total 123 employees. There is an operating, maintenance, engineering and planning group. Its primary process is to serve the distribution and storage of hydrocarbons. DHC logistics contains storage tanks (non)-floating roofs, vessels (under pressure and atmospheric), pipes, compressors and pumps.

The main hazards and risks are explosion and implosion, spills, leakage and emissions. Maintenance activities require a lot of attention for the mechanical and physical risks. To control and eliminate these risks, DSM has implemented a QESH-system (Quality, Environment, Safety and Health). The fundamental attitude in this system is that QESH has the same importance as production and financial results. Everybody has a responsibility in preventing incidents and accidents.

DSM DHC was interested in inherent safety because they wanted to improve their safety performance and to learn the new approach (inherent safety) for solving existing problems. The pilot started with an assessment, where technical, organisational and human aspects were observed.

The findings were discussed in a management meeting. Here the management of DHC reformulated the findings in their own (in-company) language. This was the input for the first workshop, where management, operators, maintenance and engineering looked at these findings from there own perspective and analysed problems by searching for inherently safer solutions. During the brainstorming sessions, 50 directions of solutions were mentioned. Five options were considered useful. In a second meeting with management, we decided to explore inherent safety by applying inherent safety methods to a longer existing technical problem of "the cooling system". The remaining 4 options were adopted by normal " task-forces" groups (the resulting impact has not been evaluated in this research). In a second workshop with participants of operations, maintenance and engineering (in total 6 participants) and with an additional cooling technology expert from TNO, we focused further on the problems with the cooling-system. During this workshop, participants learned to apply the Inherently Safer Production approach for analysing problems, and learned to understand the different perceptions of the different groups dealing with this problem. At the end of the workshop, a solution was formulated and turned into an action plan.

Adaptations of the approach

Instead of the traditional safety audit, we used the inherent safety opportunity assessment that was developed for the Hoogovens case. The assessment included organisational and human aspects. There was no external search process for technological options: external databases were not used; instead specific additional technological expertise was considered to be sufficient. In this pilot, the main adaptation was that in generating and formulating Technology Options, the main concern of the consultants was to stimulate the DSM DHC organisation to adopt an engineering approach based on Inherent Safety principles. The focus was on to try to solve the persistent problems with the cooling system. These problems were analysed by a multidisciplinary team in a special workshop, applying the principles of inherent safety to the cooling system. The feasibility study was done implicitly by the participants in the second workshop.

Options identified

An overview of the options identified, their economic feasibility, their adoption and the progress nine months after identification of the options is given in table 3.

Table 3 about here

Evaluation of the case

The commitment and the visibility of the management interest contributed essentially to the success of the pilot. The management felt responsible for inherently safer improvements. A common awareness has grown that inherently safer options could contribute to running the business more efficiently and effectively. Employees have valuable know-how and ideas and can participate in that process, making them simultaneously more responsible and motivated. Working in a multi-disciplinary team and discussing installation-related problems are of interest to everyone, and this enables the various disciplines to search for common issues. The method also developed their competence and led to better communication and co-operation, and so to a more fruitful decision-making process.

The technical solutions were focused on increasing the capacity of the cooling system, and working efficiently and effectively together leading to less maintenance work. This resulted in the elimination of some risky situations. After nine months, the action plan was not fully realised, and several technological improvements were not yet realised.

Different from the HSSP case, the initial frequency of safety incidents was already very low in this plant. The above mentioned improvements in safety management could therefore not be verified by comparing accident or incident rates over such a short period of time. Nevertheless, there are clear indications that the methodology - even without the implementation of the actual options identified - has contributed considerably to the improvement of safety management.
There is now a shared awareness and thinking in terms of inherent safety. Working in the multidisciplinary team was successful and has been accepted as a good company practice.

Case 3: Improving existing installations at ELAIS

ELAIS is the oldest and largest Greek manufacturer of edible oils and fats. The firm produces olive oils, margarines, shortenings and seed oils. It was founded in 1920 as a personal business and in 1932 it became a Societe Anonyme. In 1962, it started a business relation with the UNILEVER group, which took over some of its holdings. In 1976, UNILEVER took over the management of the company, and this resulted in a major technological and organisational restructuring. Today the company enjoys a dominant place in the local oil and fats consumer market, as well as an excellent public image.

The processes considered were: (1) the interesterification process, because the current technology used sodium methylate as a catalyst; (2) the cooling plant, because of the current technology used ammonia, (3) the hydrogenation process, because of the resulting need for gaseous hydrogen, (4) the high speed packaging line RONCHI 2 line of seed oil, because of its low operational efficiency and the resulting high rate of potentially dangerous manual operator interventions, (5) the MARG 2 packaging line of cooking fats, because of the machine-paced highly-repetitive task at the end of the line involving manual packaging and resulting ergonomic hazards.

Adaptations made in the approach

The overall approach was followed without notable alterations, apart from the difficulty of sharing the inherent safety approach with the members of the working groups. In general, the involvement of the research team as external ‘experts’ was welcome and did contribute to a fresh look at existing problems. The project team identified seven initial areas for investigation based on the inherent safety opportunity audit conducted in the frame of the project and the results of an earlier occupational risk assessment. In the case of the packaging units, a shift was observable in the methodology for technological options generation, because the specific characteristics of these units, as well as constraints set by the company team members, did not allow for ready-made alternative technologies to be investigated. Thus, in these cases, the options generation involved more hands-on work by the research team on improved design of specific parts of the packaging lines, and less literature investigation on alternative methods of packaging as a whole.

Options Identified

After the preliminary investigation, only three options were considered promising for further investigation. Two of these, the MARG2 packing line and the RONCHI2 packing line conformed to the inherent safety approach, the third being the investigation for a safer feeding and handling process of sodium methylate. This option although being more on the side of the end-of-pipe approach was retained after a request from the top management. The economic feasibility was assessed from either evidence in the literature where technologies have been in use, or from a professional judgment based on the features of the technology. An overview of the options identified, their economic feasibility, their adoption and the progress six months after identification of the options is given in table 4.

Table 4 about here.

Evaluation of the case

A critical factor affecting management staff interest in the project was the expected gains both at the business level, but also at a personal level. When members of the working groups acted only as receivers and reviewers of options, they generally presented a negative attitude towards new ideas (the "not invented here" syndrome), as opposed to when they devoted some time to the option generation. Resistance to change was noticeable mostly at line management and workers level. Their attitude can be characterised as: "if it isn't broken, don't fix it". A better communication of the top management's commitment and objectives in relation to the project down to line management could have potentially overcome this resistance.

Decision making for the implementation of promising options was affected by the relative uncertainty of the future of specific installations. For example, the hydrogenation process research was not elaborated upon because there was a clear business intention to shut down the unit in two years time. Promising results regarding the MARG 2 packing line did not proceed to implementation due to uncertainty in the continuation of the production line.

There was constant pressure from the company to investigate end-of-pipe, low-cost/fast-return safety solutions instead of inherently safer options. This was particularly evident in the interesterification plant where research was directed towards the improvement of the hazardous substance handling. A major reason for this may be the fact that ELAIS technological developments are always subject to UNILEVER approved best practices.

Overall, the team was not successful in generating enthusiasm from the personnel directly involved in evaluating and implementing promising solutions. The company commitment was apparent only in the highest level and did not extend to middle management. More frequent steering committee's meetings could possibly have a positive impact on the above.

Case 4: The Design of a Plant for Refining of Editable Oils, ELAIS

The company is the same as in the ELAIS existing plant (former case). The project deals with the inherent safety opportunities by the construction of a fully automated new plant for refining edible oil. The designed refining will take place in a *rotating disc contractor*, where a solvent flowing reverse to the oil stream (countercount flow) removes the free fatty acids from it. Only one person will be needed for the normal operation of the plant. The main hazard comes from the use of the solvent, which is miscible with water and which vapours are heavier than air and can travel a considerable distance to an ignition source and ''flash back''. The refining process makes no use of ecotoxic chemicals and produces little wastes. Therefore, it gives rise to minimal environmental concerns. However the possibility of further decreasing of solvent emissions and energy consumption was examined.

Options Identified

From an inherent safety point of view, the most promising of the options identified was the use of the high vacuum distillation method to refine the oil, which needs no solvent, is widely applied and offers significant safety, energy and environmental advantages. Despite the top management enthusiasm, those responsible for the construction of the new plant where from the beginning against the participation of ELAIS in the project. Because of the proprietary issues arisen from the innovative character of the method implemented by the new plant, they also felt threatened and kept the researchers away from relevant information.
The construction of the new plant depended upon the co-funding of the investment by the Ministry. That is why there was no progress in the construction of the new plant during the research project. The co-funding was approved about one year later and ELAIS decided not to proceed the suggested

changes, citing financial reasons. This contrasts to the results of the economic feasibility carried out by the researchers, and may rather reflect the firm's hesitancy towards the project. An overview of the options identified, their economic feasibility, their adoption and the progress twelve months after identification of the options is given in table 5.

Table 5 about here.

Evaluation of the case

The approach, slightly adapted for a new plant, and characterised by an extensive external data search, resulted in several fundamentally inherently safer technological options being identified. However, a lack of a *feeling of ownership* in the company, and a delay of the decision to build the new plant, prevented their implementation.

The overall findings of the case studies

Here we return to the three central questions formulated at the beginning of this article.

1) Does the approach lead to the identification of inherently safer (technological) options that are economically feasible?

Several inherently safer technological options were identified in all four cases, as well as more traditional safety options. The expert role of technologically oriented consultants, and an extensive external data search were important for the identification of (especially the more fundamental) options. Three factors seem to have a positive influence on the identification of options: (1) being "early in the life cycle" (e.g., at the design stage), (2) an in-company cross-functional workshop on the principles of inherent safety that includes a brainstorming session for the generation of inherently safer technological options, and (3) a facilitating role of the consultants in the option generation process. Many options proved to have short payback periods. In a period with ever-increasing competition, there seem to be some hidden but potentially very relevant economic incentives for inherent safety.
Inherent safety is associated with *greater reliability of production*, and economic optimisation of operability and maintenance of existing installations.

2) What were the strengths and weaknesses of the approach?

While the method was useful in all four cases, it had to be adapted to the specific conditions in each case. Some changes in the approach depended mainly on the life-cycle stage of the installation. Commitment of *all parties involved* is essential for the success of this type of projects. Because normally many parties are involved in the (re) engineering and construction of a plant this may need a lot of effort, but this effort pays itself back during the project. Most attention should be paid to the commitment of the party that "owns" the operation of the plant. In existing installations, the management will be mainly interested in improvements that give a return on investment within one or at most two years.

The c*apability* for generating, adopting and implementing inherently safer options varied considerably in the four cases. The advances in this capability during the course of the researchers' intervention varied even more. In the two Dutch cases, the capability was increased by the intensive co-operation between the company's personnel and the consultants/researchers in the pilot processes, especially during the workshops held to learn more about Inherently Safer Production and to generate Inherently Safer Technology Options. In these two Dutch cases, several initiatives in the respective action plans were specifically aimed at increasing the plant's capability to identify, adopt, and implement (future) inherently safer options, although the options generated in workshops with the firm's personnel were in themselves not dramatic examples of inherently safer technologies. In fact, many useful options of secondary prevention were also identified. In the two Greek cases, the consultants played an important expert role, which had a very positive influence on the generation of far reaching inherently safer options. But given this role, the consultants were not able to exert a sufficiently positive influence on the firm's willingness to adopt and implement these options or in involving the firm's personnel in the generation of options. External expertise can be used most effectively in the methodology for the initial audit, the brainstorming-process leading to improvement options, and consulting external data for more inherently safer technological options in the technology options analysis.

In the two Dutch cases - where participatory principles were used - two other strengths of the methodology came across. Mostly unexpected, in these cases the methodology contributed to improvement in SHE Management and to improve the company's and personnel willingness and capability to implement inherently safer technological options.

The options identified by the use of the methodology are not always *inherently* safer; some are in fact traditional safety options. This mix of inherent and traditional safety options could be regarded as a weakness because the company was clearly not able to make a full paradigm shift towards inherent safety. On the other hand, it is not very realistic to expect such a shift in companies with largely fixed technologies and businesses. We regard it as a strength that inherent safety principles can be applied in existing facilities, even if they are supplemented by traditional safety measures. It demonstrates that inherent safety principles can easily be integrated into safety decision-making and existing safety management procedures.

3) Are demonstration projects to stimulate inherently safer production feasible?

This study demonstrates in all four cases that, through application of the approach, substantial progress towards inherent safety can be realised in economically attractive ways. This is evidenced by the number of inherently safer technological options identified, and by the economic attractiveness of the majority of these options: many options identified were not only economically feasible, the majority had pay-back times of less than one or two years, even in the existing plants. Thus, while at the beginning the economic imperative for the adoption of inherently safer technologies is not noticeable, once options are identified they do represent economically beneficial opportunities.

The approach is useful in existing plants, but participation of the management and personnel is important in these cases. However, a company that is not accustomed to analyse and solve process-related problems on an inherent safety level, will always need a two-step approach: (1) in the first step, the fixed ideas about problem-solving are questioned: employees get an opportunity to vent their frustrations about how things went wrong in the past; during this process the attitude of the participants is changed and commitment for inherently safer production is created; (2) once the minds of people involved are 'tuned' to a new way of working and to each other, a group is formed that can start really working at inherently safer solutions. When the improvement projects are defined and the action plan is approved, the employees that took part in the workshop to generate options should also be involved in their implementation. In this way they develop a better understanding of the approach, and will maintain their commitment. Overall, we conclude that demonstration projects to stimulate inherently safer production are feasible, also in existing plants.

Discussion

Here we compare the results of this project with those of cleaner production projects, and we discuss the partly unexpected positive impact on safety management, the relevance for the Seveso II Directive, and the wider perspectives opened by our study.

Our results compared to those in cleaner production projects

To our knowledge, there are thus far no safety projects undertaken with a similar goal. That makes a comparison less useful. Therefore, we compare the results with one of the exemplary projects that contributed to the international break-through of Cleaner Production, the Dutch PRISMA project. The results of the PRISMA project are given by de Hoo et al (1991). The results of this comparison are summarized in table 6.

Table 6 around here

The table shows that in the PRISMA project, the number of options identified per company was considerable greater than in our project. This can easily be explained by the longer tradition of safety compared to environmental management, but can also be influenced by other factors like the time available, the focus on a limited or greater number of processes, etc.

With respect to the percentage of options implemented during the project, the results are strikingly the same: around 26 % is implemented in both cases. With respect to the economic feasibility, the inherently safer options seem to have an even better economic potential. This may be due to the fact that inherent safety is more closely linked with the reliability of production than cleaner production.

All together this comparison suggests that there are no scientific reasons why inherently safer design principles should not be used much more widely, especially in safety improvement programmes for existing plants. If so, requirements to pay explicitly attention to ISOA and TOA could be an integral part of any management system aiming at continuous safety improvement.

The partly unexpected improvements in safety management.

Our initial approach comprised the steps to achieve management commitment, the use of a safety audit, taking into account economic considerations and activities to facilitate decision making and implementation. These were intended links with safety management. However, unexpectedly the link with safety management turned out to be greater.

In the Dutch cases, the option generation was predominantly organised as a collective learning and inspiring effort. Working in a multi-disciplinary team and discussing installation-related problems are of interest to everyone involved, and this enables the various disciplines to search for common issues. The people at HSSP felt the first two phases of the methodology had been extremely helpful to better understand the process control and related safety problems. Without further help of the researchers they adapted several steps from the first phases of our approach and used them to tackle other problems - and with success. This is probably the explanation of the dramatic improvement in safety performance shortly after the start of the project, and before the inherently safer options identified were actually implemented. It indicates that the interdisciplinary and participatory components in the approach as developed in the two Dutch cases, strengthened the commitment to safety of the persons involved. It also indicates that the first two phases of our methodology can lead to better communication and co-operation, and so in more fruitful decision-making. In this way it can be used as a tool for safety management, and can have considerable value on their own, apart from the implementation of the (technological) options identified.

Technical installations seem static, but they usually develop gradually. Changes are made regularly and sometimes these changes are more substantial. Throughout time, gradual changes may lead to a substantially different installation. Every change does, however, not only form a potential threat to safety, but is in principle also a potential *opportunity* for the introduction of inherent safer elements in the plant. We surmise that this potential is hitherto hardly exploited systematically in safety management, but the three cases in existing plants show this potential can be great.

Relevance to the Seveso II and the IPPC Directive

The Post Seveso Guidelines (Seveso II) suggests that firms should adopt inherent safety approaches as the preferred strategy over traditional safety measures (Papadakis and Amendola, 1997). This study shows that the ISP approach can be useful in this respect. From the company practice perspective, the approach presented offers a practical and economically attractive tool that may be integrated in the company's SHE Management system. It can facilitate compliance with Seveso II and IPPC requirements.

From the perspective of the EU IPPC directive (EU1996), the present study is relevant in two ways. First, inherent safety includes environmental inherent safety.
We see inherent safety as directly complementary to the traditional cleaner production/pollution prevention approaches, because the latter usually neglects sudden and accidental releases. Secondly, the solutions database that is now being developed to support the implementation of the IPPC Directive, should preferentially promote technologies that both prevent gradual pollution *and* are inherently safer. As a second best strategy, a similar EU database of Inherently Safer Technologies could be developed.

Wider perspectives

This study basically shows that there is a great potential for methodologies on improving inherent safety that can be integrated into the safety practices of existing companies. The newly developed concept of *Inherently Safer Production*, that was developed during this project, shows itself to be viable. A basic strength of the concept is that it not only addresses technological aspects of safety, but indirectly also managerial, organisational and human aspects. In this way the Inherent Safety concept can go beyond the technological domain and may become a strategic tool for safety management.

This study was the first attempt to apply the approach and the associated tools. It involved only a limited number of cases. The tools and approach have proven viable, and they open up new perspectives, for practitioners, scientists and policy makers. The study demonstrates the wisdom of differentiating the approach for new facilities and for existing installations. We would conclude that the approach worked out quite successfully. At the same time, it needs to be more fully developed with additional experience from the field.

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Table 1, HSSP case: options identified, safety principles, economic feasibility and status after twelve months			
Options identified	**(Inherent) safety principle**	**Economic feasibility**	**Status twelve months after the generation of options**
Alternative regeneration process	Substitute process	Immediately rejected due to huge investment costs	Option noted for possible future plant
Prevention of the crystallisation of concentrated HCl	Eliminate the hazard	Pay back time less than 2 years	Realisation of a modified proposal is waiting for a quotation from a contractor
Filtration of the concentrated HCl before entering the oven	Add-on	Pay back time less than 2 years	Completed
Improved construction of the tubes leading the HCl into the oven	Substitute (instrumentation)	Pay back time less than 2 years	An improved construction was designed, but the it was decided to rebuild the total top of the oven rendering this project superfluous.
Cameras guarding the three most dangerous spots in the plant	Add-on	Pay back time less than 2 years	Completed
Computerised information on the process indicators	Simplify (instrumentation)	Pay back time less than 2 years	Project specifications defined and adopted, but not yet carried out
Improving the competence of the operators	Capabilities	Pay back time less than 2 years	Completed
New system for the technical documentation	Capabilities	Pay back time less than 2 years	Project specifications defined and adopted, but not yet carried out.
Update of the work-instructions	Capabilities	Pay back time less than 2 years	Completed
Prevention of contamination of the absorber	Elimination of risky situations	Expected pay back time less than 2 years	The proposed study has not yet been started

Table 2 HSSP Case: Development of safety and environmental performances				
	1996	1997		1998
		1e half	2e half	
Reported accidents	2	0	0	1
Reported environmental incidents	7	13	1	1
ISOA and TOA were carried out mid 1997; Implementation of options from fall 1997 till end 1998				

Table 3: DSM DHC Case: options identified, safety principles, economic feasibility and status after six months			
Options identified	**(Inherent) safety principle**	**Economic feasibility**	**Status six months after the generation of options**
Replacing the compressor to increase the capacity for cooling	Substitution, Greater margins	Not feasible	Not adopted for economic reasons
Lowering the adjustment-value of the second compressor, for two cooling systems.	Increases tolerance to human error	Feasible	Adopted in action plan.
To further investigate the materials for the valves. This should enable a better selection of valves	Capabilities aiming at the selection of Best Available Valves	Feasible	Adopted in action plan but not yet realised
Demonstrating and communicating the damage due to delayed maintenance work. This should increase the acceptance of capacity limits by other departments	Improved communication and co-operation, leading to better input	Feasible	Adopted in action plan but not yet realised.
Lowering the input temperature of C3 (from 40 to 25^{o} C)	Decrease of cooling capacity required	Feasible	This option was not adopted. It would require investments in another DSM unit than DSM DHC. This was not regarded feasible for various organisational reasons.
Check the position of the lamella and the capacity of the heat pumps and the process of heat transfer	Optimising capacity for greater margins	Feasible	Adopted in action plan.
Replace several non-return valves	Optimising capacity for greater margins	Feasible	Adopted in action plan.
Up-dating the list with technological limit values and economical minima	Improving accountability	Feasible	Adopted in action plan but not yet realised.

Adjusting tank pressure	Optimising capacity for greater margins	Feasible	Adopted in action plan.
Relabelling detection systems for passing certain pressure limits.	Improved information. Eliminating hazardous maintenance work	Feasible	Adopted in action plan
Introducing multi-disciplinary co-operation	Capabilities; improved co-operation and communication	Feasible	Realised and accepted as proficient working method

Table 4, Case Existing installations at ELAIS: options identified, safety principles, economic feasibility and status after six months			
Option identified	**(Inherent) safety principle**	**Economic feasibility**	**Status six months after the generation of options**
Using enzymes as catalyst in the interesterification process	Substitute for sodium methylate	Not feasible: the enzymes were very expensive	Rejected
Safer Handling of Sodium Methylate in closed compartment funnel	Added on safety	Feasible	This option was pressed from the beginning by the company (instead of the inherently safer alternative). Implemented after approval by the mother company
Catalytic Transfer Hydrogenation, using molecules of hydrogen donors	Substitute for molecular hydrogen	Unclear. No industrial application known	Rejected when it became clear that the company planned to shut down the unit in two years time
RONCH 2: Optimise the packaging line's operational efficiency through the analysis of micro incidents that require manual human intervention	Optimisation of existing installation	It optimises operational efficiency Regarded as *very interesting*	A pilot operational efficiency study was conducted. The option was considered as "Too exhaustive" to adopt directly.
MARG 2: Optimising the metrics of the carton packing workstation	Ergonomic intervention (minimise the repetitive strain)	Feasibility study only useful after detailed engineering	No investment made in detailed engineering
MARG 2: Various options for automation	Replacing risky work activities by automation	Very promising productivity gains at low costs	Further investigation was carried out and funds were allocated. One alternative was accepted and needed 5-10 days detailed engineering. This was delayed, due to uncertainty about the future of the line.

Table 5, Case ELAIS - Design of a Plant for Refining of Editable Oils: options identified, safety principles, economic feasibility and status after twelve months			
Option identified	**(Inherent) safety principle**	**Economic feasibility**	**Status twelve months after the generation of options**
Molecular distillation for refining edible oils	*Substitute* the process The method is also environmental friendlier	Feasible	Not used
A membrane based liquid-liquid extraction method for the removal of free fatty acids	*Substitution* of the process using a less flammable extractant (solvent)	Probably feasible, but not tested in industrial production	Not used
Extraction of free fatty acids with supercritical carbon dioxide	*Substitute*, but -to some extend- in conflict with *moderate*	Option *not* considered as inherently safer	Not used
Replacement of RDC with a more effective type of extractor	*Simplify* (no moving parts) and *minimise*	Efficiency twice that of conventional systems	Not used
Reduction of the temperature during oil pre-treatment using hollow fibre membrane extraction	*Moderate*	Feasible	Not used
Moderation of the temperature during oil pre-treatment using a specific silica absorbent	*Moderate*	Was considered outside the project by ELAIS and supplier of the absorbent)	Not used
A membrane method for the separation of the solvent from free fatty acids	Substitution of the process allowing a lower temperature *(moderate)*	Probably feasible, but not tested in industrial production	Not used
Vacuum distillation for evaporation-condensation operation at milder temperatures	Substitution of the process, allowing a lower temperature *(moderate)* Also reducing energy consumption	Feasible	Not used
Magnetic coupled	*Substitute*	Feasible	Not used

pumps to reduce the possibility of solvent leakages in the plant	(engineering)		

Table 6 **The results of this project, compared to the PRISMA Cleaner Production project**		
Results	This Inherently Safer Production project (1997-1999)	PRISMA Cleaner Production project (1989-1991)
Number of pilots	4	10
Location	Netherlands and Greece	Netherlands
Total number of options identified	36	164
Average number of options identified per pilot	9	16,4
Options implemented during the project (number, *percentage)*	9 / *25 %*	45 / *27 %*
Economically feasible options (number, *percentage)*	26 / *72 %*	65 / *40 %*
Options where feasibility was not (yet) fully assessed (number, *percentage)*	7 / *19 %*	69 / *42 %*
Not feasible options (number, *percentage)*	3 / *8%*	30 / *18%*