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# APPLICATION OF THE MODIFIED HAZOP TO AN ADVISORY SYSTEM USING RULE-BASED APPROACH FOR PACKED COLUMN

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**Abstract.** An advisory system using a rule-based approach has been developed in which the knowledge required to perform hazard identification is divided into process-specific and process-general components. Hazard identification has been carried out using the modified Hazard and Operability Study (HAZOP) method. In the proposed modified HAZOP, the two study nodes are connected in one mode of analysis. The process-specific knowledge, which consists of a conventional HAZOP study result, has been stored in the database. The process-general knowledge consists of rule-based which has been developed from the result of process simulation. The combination of hazard identification technique with process simulation result is important, in order to analyse the causes and consequences of the deviation in the process. For hazard identification, the process deviations selected are flow rate, temperature, and pressure. An inference engine for this advisory system has been developed using Visual Basic programming language, for appropriate interaction between knowledge-based components, in order to identify process-specific of causes and consequences for each process deviation specified. The procedure is based on the proposed HAZOP algorithm modified from a conventional HAZOP. The case study used is a packed column of an oleo chemical plant. The study has contributed to an improvement of hazard identification technique, which proposed a modified HAZOP algorithm by considering the consequences of the operation for each process deviation. The modified HAZOP algorithm has been proposed in a generic manner, however, the advisory system developed in this study is limited to the application for packed column of oleo chemical plant only.

*Keywords:* Hazard identification, advisory system, ruled based, process simulation, packed column

## 1.0 INTRODUCTION

In the assessment of risks (including the plan to reduce or control risks), hazard identification is one of the first important elements. Among the methods used to identify hazards are Process Hazard Analysis (PHA), Concept Hazard Analysis (CHA), What-If Checklist, and Hazard and Operability Study (HAZOP). However, HAZOP is the most widely applied method for the identification of hazards in the process industry [1].

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In general, HAZOP is a method which systematically and critically examines each possible process deviation. The objective is to identify all deviations from the design intent, and subsequently the causes, consequences and finally, to suggest the remedies.

The existing HAZOP procedure may not cover all types of hazards and risk factors. A major problem with HAZOP relates to the level of detail in the study, especially in carrying out hazard analysis in a complex process and developing the linkage propagation of the fault or hazard identified, to each operation unit in the plant. Most of the HAZOP studies carried out currently have not considered the relationship between two or more streams in detail. This may lead to an incomplete analysis of the process deviations. Consequently, it may also affect the qualitative and quantitative aspect of risk analysis.

In parallel, the level of details and quality of the overall result produced in HAZOP study depend on the availability and usage of plant documentation or process descriptions as well as expert knowledge, involved in the study. Even if these descriptions cover the main parts and subsystems of a plant, a systematic link is lacking between the plant description and the search procedures used in the identification methods of operational hazards. Doubts are therefore raised about the systematic and coverage of the results of hazard identification method used generally, and HAZOP analysis in particular [2]. Therefore, there is a strong interest in the potential for emulating HAZOP by a computer. Emulation of HAZOP could have a number of benefits, for example, it may allow a project team to bring forward what could otherwise delay, or arise from conventional HAZOP study. At the same time, there have been substantial development in the computing technologies that could bring about such emulation [3]. One way of doing this would be to incorporate the knowledge used in the analysis into an intelligent computer system called 'expert system' [4]. Therefore, it is intended in this research to study common hazards normally encountered in the process, and develop a new algorithm as a support procedure based on expert system approach as well as to restructure the HAZOP study documentation. This effort hopefully can improve the technique of hazard identification in HAZOP study.

## 1.1 Basic Concepts of Hazard and Operability (HAZOP) Study

A HAZOP study identifies hazards and operability problems. The technique involves investigating how the plant might deviate from the design intent. The purpose of HAZOP is to identify potential hazards before an incident occurs, not necessarily on solving how to eliminate or minimize the potential hazards. In general, HAZOP is to review the plant in a series of meetings, during which a multidisciplinary team methodically 'brainstorms' the plant design, following the structure provided by the guidewords and the team leader's experience. The other members of the team are the project manager, the operations representatives, and also the safety representatives. The team concept suffers if a member is removed for other duties while being involved in the HAZOP review. The team focuses on specific points of the design (called 'study nodes'), one at a time. At each of these study nodes, deviations in the process parameters are examined using guidewords. The guidewords are used to ensure that the design is explored in every conceivable way. Thus the team must identify a fairly large number of deviations, each of which must then be considered so that their potential causes and consequences can be identified.

The guidewords shown in Table 1, are the ones normally used in HAZOP analysis. Each guideword is applied to a process parameter as shown in Table 2.

**Table 1** HAZOP guidewords and their meanings

| Guidewords | Meaning |
|---|---|
| No | Negation of the design intent |
| Less | Quantitative decrease |
| More | Quantitative increase |
| Part of | Qualitative decrease |
| As well as | Qualitative increase |
| Reverse | Logical opposite of the intent |
| Other than | Complete substitution |

**Table 2** Application of guidewords to process parameter

| Guidewords | Parameter | Deviation |
|---|---|---|
| No | Flow | No flow |
| More | Pressure | High pressure |
| As well as | One phase | Two phase |
| Other than | Operation | Maintenance |

HAZOP study needs to be done in a friendly, effective, and professional manner, in order to reduce the probability and consequences of a major accident which could have a detrimental impact on the individuals, properties, environment, and most importantly, on the company itself for its survival and continual business operation. Therefore, it is essential for the management to address HAZOP's recommendations, especially to those that are associated with the highest risk or more threatening to life.

## 1.2 An Overview of Advisory System

In the advisory system proposed, a rule-based expert system approach will be followed. There are many definitions given to describe an expert system. In general, expert system can be defined as a computer program that encodes the knowledge of an expert in some specific areas and uses inference procedures in solving problems that are difficult enough to require significant human expertise for their solution. Specifically, an expert system is a computer system that simulates the learning, memorization, reasoning, communication, and action processes of a human expert in a given area of science, giving in this way a consultant that can substitute a human expert with reasonable guaranties of success [5]. Therefore, the ultimate aim of every expert system is the substitution of the human expert and improvement on their performance. The roles that need to be played by expert systems are diverse and they mainly correspond to those played by human experts, such as providing information, solving problems, and giving explanations.

The structure of an expert system can be divided into domain-specific knowledge and domain-independent knowledge. Domain-specific knowledge comprises of the expert's factual and heuristic, rule-oriented, and structure-oriented knowledge. Meanwhile, the other represents general problem-solving strategies applicable to any set of domain-specific knowledge built into the system [5].

Furthermore, this domain-independent problem-solving ability is based on an inference engine that can deduce various results, based on input facts and the expertise captured in the knowledge base. The engine is usually composed of an interpreter, which analyzes the current state of the inference process, and a scheduler, which sequences the actions taken by the inference engine. In detail, the role of the rule interpreter in the inference engine is to continually evaluate all rules in the system to locate those whose conditions are satisfied. The scheduler then orders the firing of all such rules. Many schedulers employ meta-rules to provide the principles that determine in what sequence rules should be fired in [5].

The inference engine mechanism employed in the expert system must be compatible with the data structure form used to represent the domain knowledge. One of the key features of expert system technology is the distinct separation of the domain-specific and domain-independent aspects of knowledge, allowing much greater ease in updating or modifying the knowledge base [5].

In general, the procedure of extracting knowledge from an expert and encoding it in program form is called 'Knowledge Acquisition'. Basically, knowledge acquisition is the heart of the expert system development process. Most of the time a second person, called an analyst or 'Knowledge Engineer', is required to communicate with the expert and the program. The knowledge engineer's job is to act as a go-between in helping an expert to build a system. Knowledge acquisition is a critical part in the construction of an expert system [6]. Therefore, the implementation of an expert system needs to be constructed through several stages. Based on the COGNITECH method, implementing an expert system can be broken down into four parts and they are [6]:

(i) Quick development of a demonstrator, to establish the feasibility of the project and also the conditions for the final product.
(ii) A test prototype.
(iii) An advanced demonstrator.
(iv) Construction and putting into service of the final product.

## 2.0 METHODOLOGY

The proposed flow diagram of an advisory system framework for the modified HAZOP is shown in Figure 1.

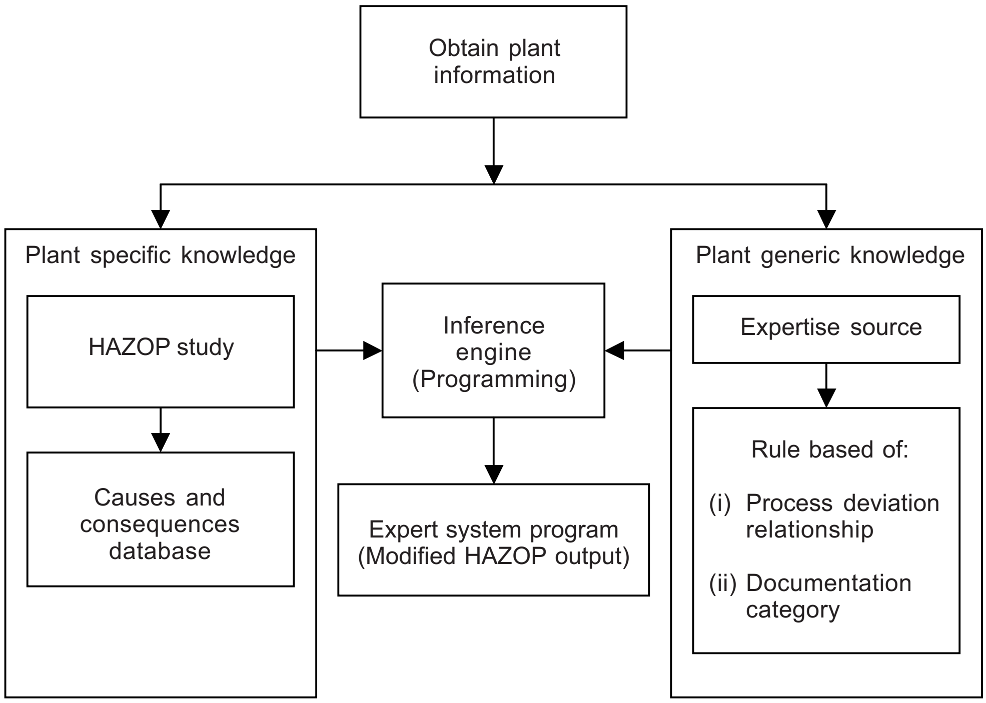


**Figure 1** Framework of an advisory system using modified HAZOP

Obtaining plant information is the basis for developing the knowledge base. This would include a piping and instrumentation diagram (P&ID), description of the process, and also mass and energy balance of the process.

### 2.1 Development of Plant Specific Knowledge-Based

The plant specific knowledge-based is developed from the result of HAZOP study. The HAZOP study result will be used in supporting and clarifying the causes and consequences information of a process deviation specified. Even though the development of the plant specific knowledge-based is derived from the conventional HAZOP study, nevertheless, the result stored in this knowledge-based could be different from the typical structure. This depends on how the knowledge is used and the capability of the tools building up this plant specific knowledge-based.

## 2.2 Development of Plant Generic Knowledge-Based

The core of the proposed advisory system is the set of rules in the knowledge base. In the production rule-based, experts often express their knowledge informally as "Well, since A, B, and C have occurred, so then D, E, and F", "While X or Y is present, we proceed with Z," or "If A and B or C are present, then this indicate that the fault is probably in D". These sets of conditions and actions can be captured in the form of IF/THEN rule statements. This is the most widely used expression for representing knowledge in the current expert system technologies. Each rule consists of a condition part A and an action part C, and is of the form: 'If A Then C'.

Thus, the main function of plant specific knowledge-based development is to store all rules that have been developed for the application of an inference engine as to deduce for output solution. The development of rules is essentially based on the result of knowledge acquisition process. The proposed algorithm of the modified HAZOP is shown in Figure 2.

The algorithm proposed consists of three main phases. The first phase involves the conventional HAZOP study procedure. The system is divided into several study nodes. After selecting a node, the application of guidewords is performed, and all possible causes and consequences are recorded. The study will finish only if the information related to the process deviation is confirmed and accepted by the HAZOP team members.

In the next phase, two steps are involved. The first step is to select another study node to be analysed together with the previous study node. The second step is to analyse both study nodes to obtain the relationship between them. This phase will be carried out only if there are identified causes and consequences performed correspond to the process deviation specified in the first phase. There are two main outputs produced. The first output will identify the type of process deviation for both streams. The second output will take the analysis back to the beginning of the procedure, as there is no more identified process deviation obtained.

In the last phase, the type of both study nodes, which have been connected in section two, will be characterised in term of input-output concept. If this study node has been identified as the input-type, consequently all the main consequences information of the other study node specified in phase two would be determined as the side consequences for the study node in phase one. On the other hand, all the main causes of the second study node will be recognised as the side causes for the specified study node of phase one. If everything completes, the procedure returns to phase one.

In Figure 2, there are two steps for decision-making that have been structured in both phase one and two, which have to be performed in order to connect those study nodes specified. The step involves will decide whether an identified process deviation relationship has been obtained or not, based on both of study nodes specified earlier. After the relationship behavior is identified, it will continue as to categorize the

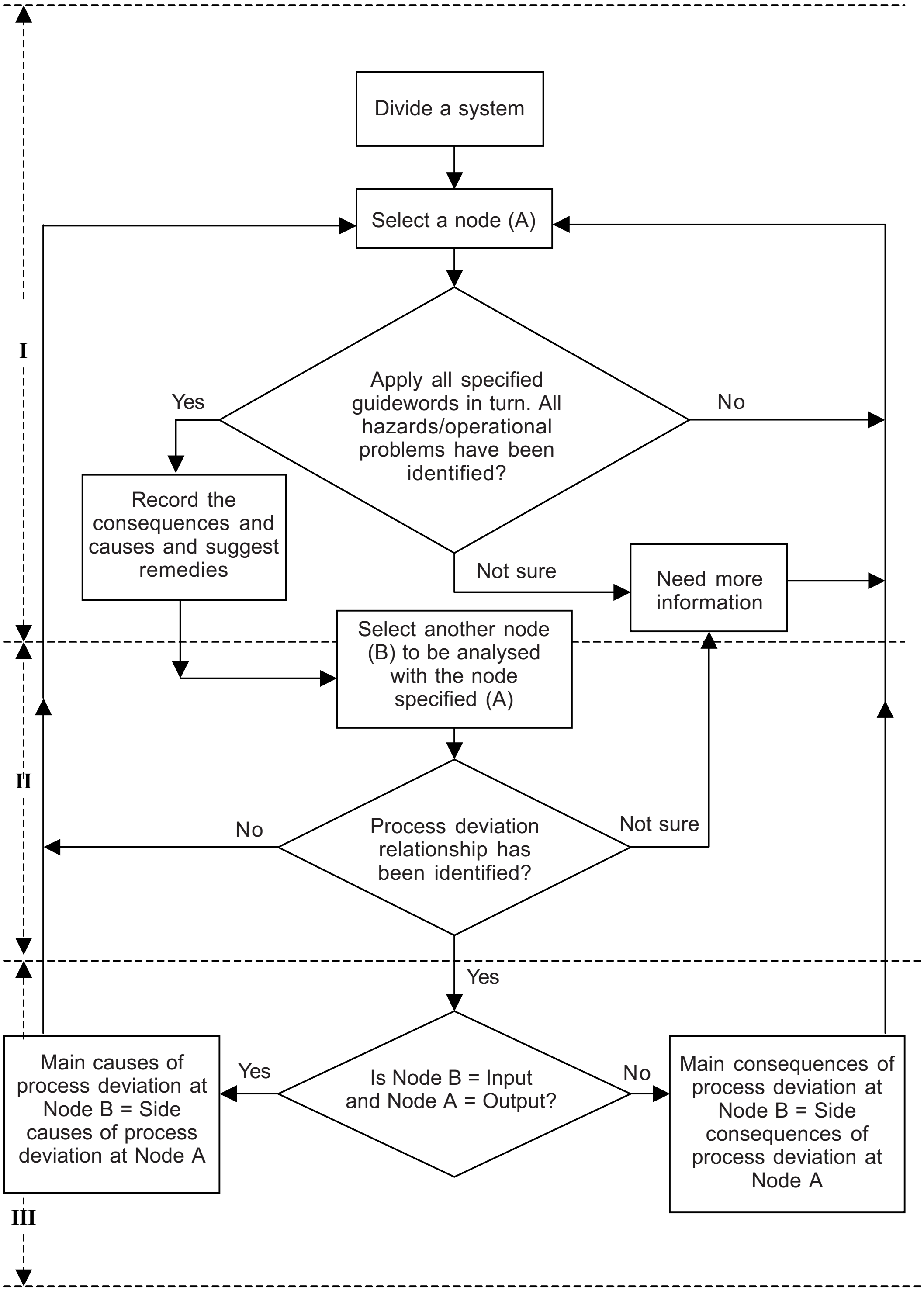


**Figure 2** A proposed algorithm for the modified HAZOP

information obtained into a side causes or side consequences group. The decision-making process task is needed as the step has to deal with various kinds of mode analysis. As a result, the knowledge acquisition process could be used to conduct the required decision-making process.

In acquiring knowledge, the knowledge engineer proceeds through several stages before producing an advisory system as shown in Figure 3 [7].

In general, developing an advisory system comprises of two main phases. The first phase involves all the tasks of identifying, conceptualizing, formalizing, implementing, and also testing of an appropriate architecture for the system. The second phase deals with the revision stages that will reconstruct the system and it involves reformulating, redesigning, as well as refining task.

Finally, the rule-based developed is used to characterise the relationship between the process deviation based on the two study nodes specified earlier. They also form the basis to separate all the information obtained into a number of information group, which are based on the identified process deviation relationship.

## 2.3 Development of Inference Engine

The inference engine will use the information stored in the plant specific knowledge-based as to show the related knowledge that associate to the rules or solutions that has

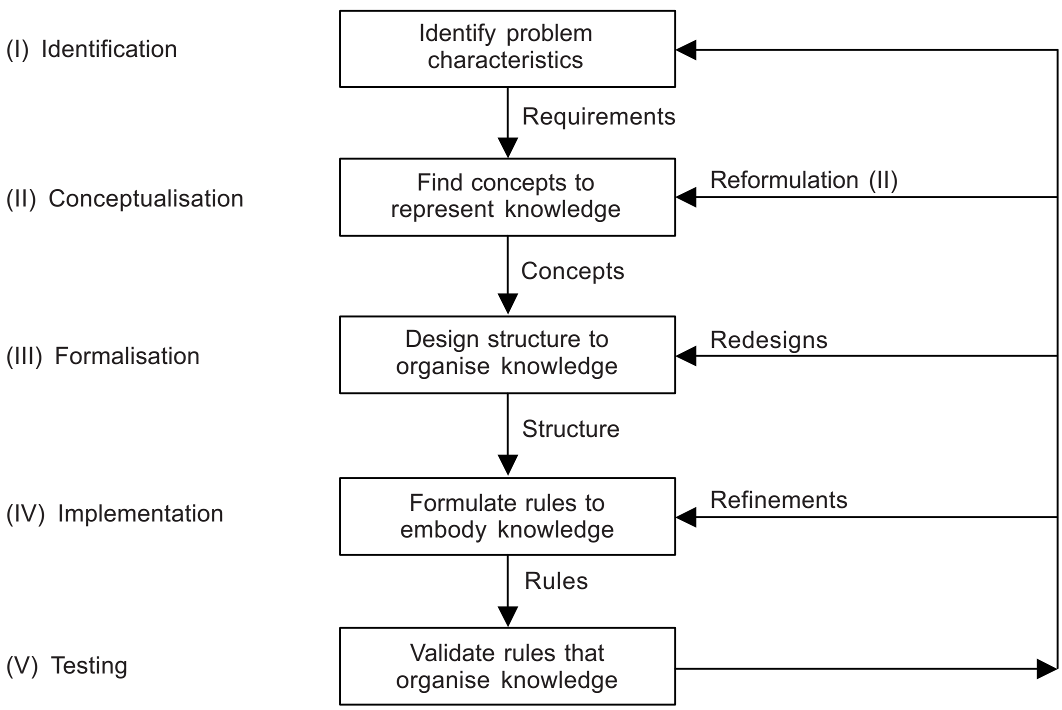


**Figure 3** Major stages of knowledge acquisition process [7]

been satisfied in the plant generic knowledge-based for the final results. The development of the inference engine is essential as it integrates both knowledge bases developed earlier. It is based on the concept of computer-aided approach. It deals with a lot of programming task and has to be based on the rule chaining stored in the plant generic knowledge-based. This study will not only use the forward-chaining problem-solving approach but also the heuristics strategy for deduction of the intended solution.

## 2.4 The Case Study

The proposed advisory system using the modified HAZOP will be applied to a case study. The main objective of the case study is to demonstrate the application of the advisory system's framework proposed for various modes of analysis in HAZOP study, using several guidewords. The packed column of oleo-chemical plant has been selected as a case study as shown in Figure 4. Dehydrated crude fatty acid from palm kernel oil contains all fatty acid fractions from C6 to C18, plus a residue. The feed to the fractionation unit comes from the hydrogenation unit or storage. The feed to the pre-

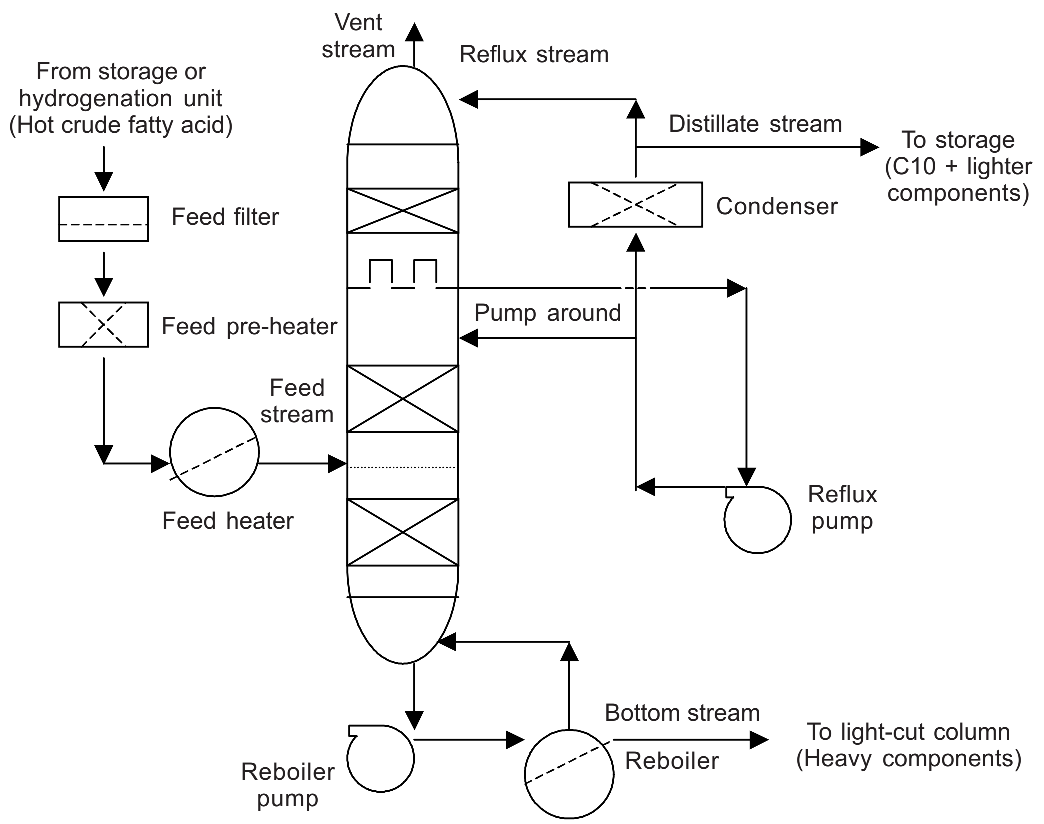


**Figure 4** Packed column (Pre-Cut fractionation column) of Oleo-chemical plant

cut column first passes through the feed filter. The filtered feed is then heated in the feed pre-heater, a plate and frame heat exchanger, by hot crude fatty acid and finally in the feed heater, a shell and tube heat exchanger. The feed enters the pre-cut column between the rectification and stripping section. It is then flashed into the pre-cut column. The vapors, consisting of the C6, C8, and C10 fractions are condensed by direct contact in the pump around section of the column. The condensed distillate is pumped by the reflux pump and cooled by tempered water in the condenser, a plate and frame heat exchanger before being returned to the top of the pump around section. Part of the hot distillate is sent as reflux to the rectification section of the column. The net distillate is pumped to storage under level control. The bottom products are pumped by the bottom pump and heated by hot oil under pressure to suppress vaporization in the reboiler, which is a shell and tube heat exchanger. The net bottom product is pumped to another column. Vacuum is maintained at the top of the column by the second stage of the precut column ejector. The main product of this column is to recover C10 and lighter cut at the distillate section as well as other heavy components at the bottom line, to be separated at later stage of fractionation system.

The relationships between the feed and output streams (bottom, vent and distillate) of packed column will be developed using rule-based method.

## 3.0 RESULTS AND DISCUSSION

The discussion of results is divided into three main sections. The first section discusses the output produced from the application of code programming and the relationship with the rules developed. The next section presents the comparison of results between the modified and conventional HAZOP study. Finally, the evaluation results of an advisory system is presented in the last section.

### 3.1 Outputs of the Advisory System and the Rule-Based Developed

There are two types of production rule-base developed in the testing stage of knowledge acquisition process and they are the true rules and false rules category. The true rules category contains all rules, which identify a type of process deviation relationship as shown in Figure 5.

From Figure 5, there are three HAZOP categories; they are the main causes category, main consequences category, and side consequences category. Both main causes and main consequences category referred to less flow guideword selected, and this is the basic structure of the conventional HAZOP study documentation. The side consequences category, on the other hand, is produced from the result of identified process deviation relationship. The false rules category includes all rules that have not identified any deviation relationship at all (no deviation condition) as shown in Figure 6.

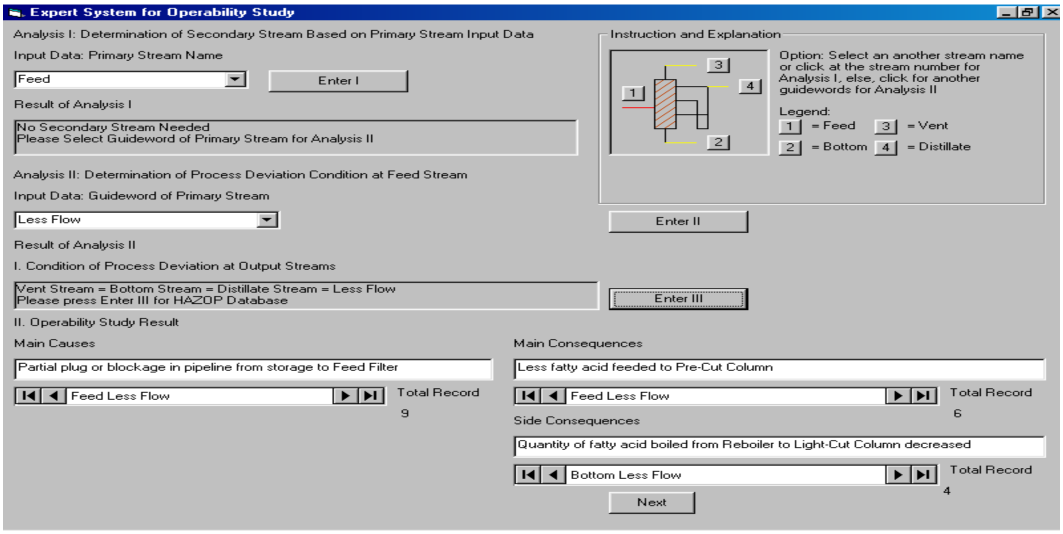


**Figure 5** HAZOP database for less flow in feed stream

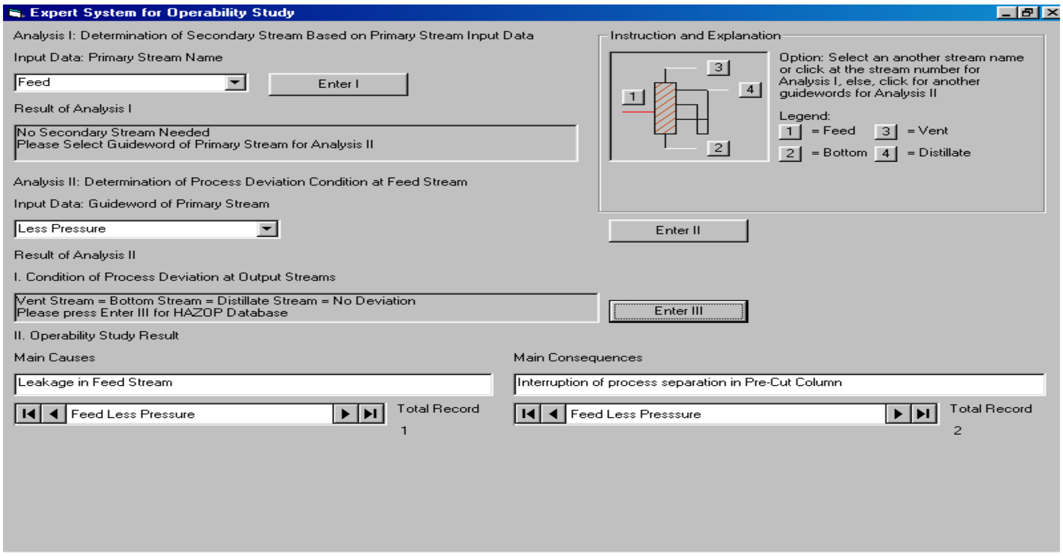


**Figure 6** HAZOP database for less pressure in feed stream

Figure 6 shows the false rules category result such as less pressure deviation which has been identified not to produce any process deviation to other streams. Consequently, the program developed will show 'No Deviation' as the result and there are only two types of HAZOP categories shown and they are the main causes and main consequences category. There is no side consequences category as shown in Figure 5.

### 3.2 Comparison between the Modified and Conventional HAZOP

When using the modified HAZOP study proposed, the number of causes and consequences based on the true rules category has increased compared to the same analysis using the conventional HAZOP study. This comparison is shown in Table 3.

**Table 3** Modified and conventional HAZOP study results for feed stream

| Process deviation | Modified HAZOP study result | | Conventional HAZOP study result | | Rules category |
|---|---|---|---|---|---|
| | Causes | Consequences | Causes | Consequences | |
| Less Flow | 9 | 17 | 9 | 6 | True |
| More Flow | 5 | 13 | 5 | 5 | True |
| Less Temperature | 8 | 12 | 8 | 2 | True |
| More Temperature | 6 | 12 | 6 | 3 | True |
| Less Pressure | 1 | 2 | 1 | 2 | False |
| More Pressure | 1 | 4 | 1 | 4 | False |

Using the modified HAZOP in the advisory system for feed stream, there are four types of process deviation which produce more consequences compared to the conventional HAZOP. These process deviations are from the true rules category namely less flow, more flow, less temperature, and more temperature. However, the number of causes produced from the modified HAZOP are still similar to that of the conventional HAZOP study. Meanwhile, two relationshi ps from false rules category, which are less and more pressure deviation, produced similar number of causes and consequences compared to the conventional HAZOP.

### 3.3 Evaluation of an Advisory System Results

The main purpose in evaluating all the outputs from an advisory system developed is to validate whether the methodology used has significantly supported the modified HAZOP algorithm proposed. From the result, the advisory system application has been validated to produce an excellent tool for demonstrating as well as to support the new HAZOP algorithm proposed, based on the following factors:

(i) All rules which contribute to the final result documentation is being provided on the program interface developed.
(ii) All the related input data are shown clearly on the program interface developed.
(iii) The result of each step in the modified HAZOP algorithm proposed is shown specifically on the program interface developed.
(iv) The final result of the expert system program is shown according to the type of input data entered by the user.
(v) The analysis of the program can be repeated rapidly and the information stored in both knowledge-based structure can also be updated.

As a result of connecting two study nodes for one mode analysis in the HAZOP study, the modified HAZOP documentation structure has been produced. This HAZOP structure is compared with the conventional HAZOP documentation structure using the Analytical Trees application. From the development of analytical trees based on the conventional HAZOP documentation structure, it is proved that there is no connection between the structures developed. Each analytical tree only considers the main causes and consequences related to the mode analysis being analyzed. However, the development of analytical trees structure for the modified HAZOP produced by the advisory system program has shown some differences in behavior compared to those structures, as demonstrated in Figure 7.

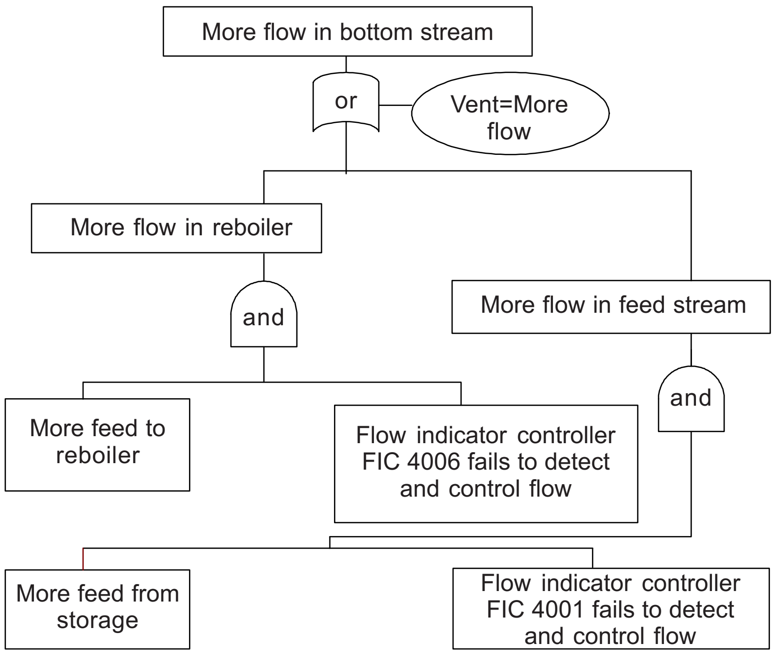


**Figure 7** Analytical trees structure for more flow-more flow analysis in bottom stream based on the advisory system result

Figure 7 shows that more flow deviation of feed stream has been identified as the side causes, which produce more flow deviation for bottom stream. The feed stream main structure has been developed to the main structure of bottom stream to show that more flow deviation of feed stream is specified as one of the causes, which can produce more flow deviation for bottom stream. In summary, Figure 8 has indicated that there are two major improvements produced.

(i) The development of analytical trees based on the modified HAZOP documentation structure produced from an advisory system developed has combined various sources of stream analysis information.
(ii) The combination has been made through the *or-gate* object, which means that they are only connected based on the process deviation relationship that has been identified.

## 4.0 CONCLUSIONS

The advisory system proposed is using a rule-based approach. The system stores the modified HAZOP results in the knowledge-based structure and then use the Visual Basic programming to develop its inference engine. The main improvement made by the modified HAZOP is that it contains main and side causes, and consequences related to the specified guidewords from other study nodes.

However, this advisory system is not intended for general industrial application. It is a preliminary development to demonstrate the application of the modified HAZOP when compared to the conventional HAZOP.

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