A New Semi-Automated HAZID Method for More Comprehensive Identification of Hazardous Scenarios

Sunhwa Park*, Amol Jayant Bansod, Hans Pasman, William Rogers, and M. Sam Mannan

Mary Kay O'Connor Process Safety Center, Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, TX 77843-3122

*corresponding author: sunh9@tamu.edu, +1 979-985-7448

Despite the substantial development of HAZID methods, traditional HAZID tools still need further development because of their weaknesses in identifying possible hazards. Despite many measures, still continual catastrophic events occur, even after reviewing potential scenarios with HAZID tools. Therefore, it is evident that unintended incidents that occasionally occur in the process industries, in order to prevent, require more enhanced HAZID tools. With this new HAZID methodology, this study seeks to identify possible scenarios with a semi-automated system approach. Based on the two traditional HAZID tools, Hazard Operability (HAZOP) Study and Failure Modes, Effects, and Criticality Analysis (FMECA), the new method will minimize the limitations of each method. Additionally, rather than depending on the HAZID tools to achieve the connectivity information of the process system, this study will consider obtaining in prepopulated sheets connection of linked components by means of new advanced technologies before applying HAZID tools. Next, this method can be integrated with proper guidelines regarding process safer design and hazard analysis. To examine its usefulness, the method will be applied to a case study.

Keywords: semi-automated HAZID, HAZOP, FMECA, DATA Mining, Safeguards, SQL, SmartPlant P&ID®

Backgrounds and research directions

Process Hazard Analysis and Regulation

Many companies in the process industry endeavoured to prevent possible hazardous events with Hazard Identification (HAZID)[1] methods. This has been either on their own initiative so that the positive outcomes can help them obtain more commercial competitiveness, or the application is required under government regulations (CCPS, 2008).

The limitations of current PHA

Despite the usefulness of Process Hazard Analysis (PHA), current PHA methods as mentioned in OSHA Regulations (1992), have limitations. For instance, as Hendershot (2006) asserts, the regulations grant the freedom to select one from among various PHA techniques, because employers must find the most appropriate methods for their plant. In other words, there are no clear guidelines for selecting optimum PHA techniques, which mainly depends on experience. Table 1 shows the general limitations of current PHA (CCPS, 2008; Seligmann, 2011).

Table 1. Classical limitations of Process Hazard Analysis

Category	Issue	Description
Nature of the method	**Completeness**	There can never be a guarantee that all incident situations, causes, and effects have been considered
	Inscrutability	The inherent nature of some hazard analysis techniques makes the results difficult to understand and use
Nature of the analysis team	**Reproducibility**	Various aspects of hazard evaluations are sensitive to analyst assumptions; different experts, using identical information, may generate different results when analysing the same problem
	Relevance of experience	A hazard analysis team may not have an appropriate base of experience from which to assess the significance of potential incidents.

[1] Herein, HAZID means generally hazard identification, and does not refer to a specific tool.

Subjectivity	Hazard analysts must use their judgment when extrapolating from their experience to determine whether a problem is important

The first limitation, completeness, is the most dominating one, as quite some accident scenarios have not been recognised as possible before.

Analysis of CSB reports[2]

As an independent federal agency, the U.S Chemical Safety and Hazard Investigation Board (CSB) has investigated incidents in the chemical industry since 1998. These exhaustive investigations are dealing with only the more serious chemical industry events. Nevertheless, the reports reveal multiple clues for identifying commonalities among process events, which is particularly pertinent for finding the root causes; the analysis of Baybutt (2016a) and Kaszniak (2010) represent the possible root causes of reported incidents by the CSB.

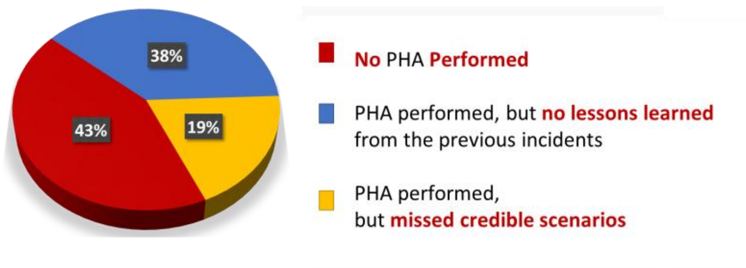


Figure 1. The analysis results of Kaszniak (2010)

Of the forty-six CSB reports published between 1998 and 2008, Kaszniak (2010) pointed out that twenty-one cases were directly associated with PHA. Figure 1 shows the distribution of the twenty-one cases concerning PHA; 43% (9 in 21) of cases fall into "No PHA performed." 38% (8 in 21) are categorized as "no lessons learned" during PHA, and 19% (4 in 21) are described as having "no credible hazard scenario at PHA". Specifically, in about 57% of incidents where a PHA had been performed before the incident, past experiences and conceivable scenarios had been overlooked. These observed data represent the perception of whether a current PHA has worked acceptably well.

Furthermore, Baybutt (2016a) stresses other common aspects of incidents reviewed by the CSB. In particular, he states that there were many failed cases of proper process designs (28%) and safeguards (56%) of the incidents. Since these insufficiencies are prone to be related to the initial design, the competency of design and process engineers is crucial. Additionally, necessary safeguards were not applied, so the hierarchy of process control, shown in Figure 2, was not applied effectively. Hence, the analysis of Baybutt (2016a) provides suggestions for a better safety control system.

Baybutt (2015a) analysed the types of failures and flaws of the primary tool of PHA, the hazard and operability study (HAZOP), probably the most applied HAZID tool used in the worldwide chemical industry, One of the many causes of flaws is that in the HAZOP procedure deviation of a process variable is selected first, then in backward direction is sought for the cause or causes, and subsequently in forward direction shall be determined in what consequence it will result. While in human thinking one tends to start with a cause and then look for the effect. He also summarized what requirements are to be demanded of the competence of the team members conducting a HAZOP (Baybutt, 2015b).

[2] Rather than HAZID, this section uses the PHA term, which has a US regulatory connotation, because this section mentions reports from the CSB, a U.S. federal agency.

Inherently safety
Passive safeguards
Active safeguards
Procedural safeguards
Personal protective equipment
Emergency response

Figure 2. Hierarchy of Safeguards

Adopted from Baybutt (2016a)[3]

Aims of the method

Attempt to achieve an enhanced HAZID tool

To achieve a useful HAZID tool, this research proposes a new methodology for more systematic and semi-automated approaches. Rather than focusing on the specific parts of a system, a holistic system analysis has the strength of identifying the actual root causes and consequences of incidents. Furthermore, with a comprehensive view, process safety management can suggest ideal guidelines to their employees so that likelihood of possible incidents will be decreased. Furthermore, during a HAZOP meeting, there are too many repetitive tasks, which makes it tedious for participants and makes them less aware of possible scenarios that require more intensive attention. To minimize repletion and encourage involvement, this study seeks a semi-automated approach to reduce wasted time and give better attention to critical points.

Practical guidelines

As shown in Figure 2, process design and engineering with respect to plant and safeguards play the most fundamental roles in avoiding adverse events, which can have impacts on process safety (Baybutt, 2016b). This study pursues a more practical method to help process engineers with process safety designs, even at the initial design stage. Therefore, a new tool should help to create an inherently safer design with passive and active design safeguards.

The application of cutting-edge techniques

Currently, new technologies facilitate the development of safety techniques. To date, new technologies developed by other disciplines have mainly supported chemical plant control or optimization through, for example, automation and simulation programs. However, it is time to apply several cutting-edge technologies designed to enhance safety of the process industry. For instance, the commercialized process package, *Smart Plant Piping and Instrument Diagram®* (SP P&ID®) can be applied for better results in the context of safety considerations, whereas its primary application is for effective design efforts. Additionally, this study will briefly employ other computer science and statistics methods and tools, to deal with valuable data for a new HAZID tool.

Current attempts for integrated HAZOP and FMEA

Blended HAZID (BLHAZID)

On the basis of the system approach, Functional Systems Framework (FSF), Seligmann (2011) and Seligmann et al. (2012) developed an efficient integrated methodology, called Blended Hazard Identification (BLHAZID). This effort proposed blending results of two HAZID tools, HAZOP, and FMEA. Their heavily computerized method applies a structured language that enables implementation of a system approach since it has a broad range of coverage (plant, people, and procedure) and holds causality knowledge in triplets.

[3] Baybutt (2016a) describes a hierarchy of safeguards as seven criteria, including an additional category, ‘segregation and separation’, filling the space between inherently safer design and passive safeguards. However, we did not include this category in Figure 2, because it has overlapping aspects with other categories and some experts assert even that inherently safer design incorporates the meaning of segregation and separation.

Process Flow Failure Model (PFFM) Analysis

The works of Ego and MacGregor (2004) and MacGregor (2013) introduced a new methodology, Process Flow Failure Model (PFFM) Analysis, which in character is between HAZOP and FMEA. As the name implies, the concept of PFFM is to maximize the guide variable of the process flow, because the way of thinking is similar to the reasoning of operating personnel (Ego & MacGregor, 2004). MacGregor (2016) claimed that PFFM is an efficient and straightforward method compared to a HAZOP study, as it influences participants to be more active during a PHA meeting. PFFM can increase completeness of scenarios identification significantly, in case studies more than a doubling of the number of scenarios has been demonstrated.

Methodology

Rather than separating each component of a system, their combination enables people to imagine the bigger picture of functioning of an ensemble in the system; this holds in general, but certainly for a plant in which components may be connected over relatively large distance and in a complex way. This chapter proposes a new method for deriving this overall insight that will enhance hazard identification with respect to chemical plants. For a comprehensive understanding, a critical point is deriving the proper connections among linked components of a system from the Piping and Instrumentation Diagram (P&ID) material, based on the fluid direction. Through defining and describing these links in the analysis sheets, the limitations of HAZOP and FMECA methods will be attenuated. This will also help to reduce the drawback in the HAZOP procedure of missing cause-effect relations because of initiating at a deviation and having to search back against flow direction for a cause.

Building stones of this study

Overall, as shown in Figure 3, this study highlights an integrated relationship of the following three factors: process data, applications of the relevant data, and proper HAZID tools. Keeping in mind that any one factor is not entirely responsible for the prevention and/or protection of possible incidents, this study attempts to achieve more intertwined research attributes - correlations among process information, previous experiences, and appropriate current theories to develop more systematic approaches based on lessons learned.

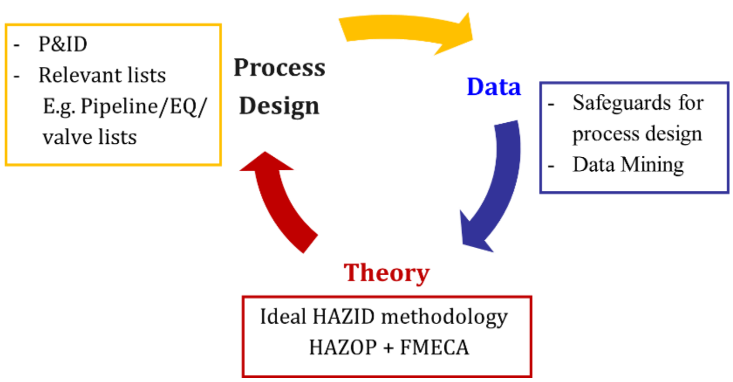


Figure 3. Overall Concept of the New Methodology

Main concept of this study

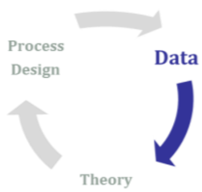
We know that P&IDs and associated process documents serve besides others the fundamental role in the process industry of indicating the intended process conditions. Process engineers make or develop these documents based on a process design scheme, particularly giving more weight to the process perspectives, such as process optimization, than to safety aspects. Whenever they perform HAZOP and FMEA, PHA teams review the current process designs and the process conditions by employing the multiple documents simultaneously. Because of this multiplicity of documents, consistency in the information should avoid confusion and misunderstanding.

However, there are likely to be burdensome aspects in dealing with the multiplicity of process papers. Worst of all, humans are prone to errors, so there might be inconsistencies among different documents (e.g., the line list and its P&IDs). In addition, it takes a considerable amount of time to review all data while conducting a HAZID meeting. In general, engineers should be ready to open any relevant documents during a HAZOP study and to respond to the information, rather than to review incorrect data under time-sensitive conditions.

Introduction of SP P&ID®

Recently, a cutting-edge software, Intergraph's SmartPlant Piping and Instrumentation Diagrams® (SP P&ID®), has been commercialized by Intergraph. It not only represents the process diagram, like AutoCAD® P&ID, but also encompasses various data, so it enables the handling of process data and symbols simultaneously. In addition, there are significant benefits such as saving time and presence of highly accurate data, with SP P&ID® in comparison with older packages. Consequently, SP P&ID® can manage a wide range of process data and figures of typical P&IDs, so it enables engineers to use the data effectively. The following section will provide a description of how to use this data properly for the purpose of hazard identification.

Application of valuable data



The purpose of this section, associated with the application of data, is twofold: to deal with the process data in the process industry and to employ previous experiences regarding safeguards. First, interested data can be extracted with the aid of SP P&ID® so that it will help to achieve a simpler and more consistent semi-automated analysis. Accumulated previous experiences, herein taken from the CCPS book (CCPS, 1998), *Guidelines for Design Solutions for Process Equipment Failures*, will be employed for more inherently safer designs and safeguard recommendations.

Connectivity of process plant

To date, in almost all process plants, discrete process documents have conventionally been managed as Microsoft EXCEL files. In other words, in chemical plants few attempts are made of data mining to deal with their process data effectively; only the correctness of each input documentation was satisfied. Hence, this study will conduct a data mining operation to extract valuable information hidden in the data mass by applying with Structured Query Language (SQL) of Microsoft® SQL Server 2012 program®. The following subsection explains which data can be mined.

Our body maintains its health when its organs and physical structures are working properly with blood vessels, which make links throughout the whole physical structure. Analogously, in the process industry, pipelines might be regarded as the blood vessels of chemical plants, since they connect all process components; almost all plant elements have connections with piping and piping components so that an overall process system can be recreated based on the links. For this reason, when process engineers make a process document for any process component, it is common to report the associated piping numbers to designate an accurate location of each item. Generally, all the lists for pipes, equipment, and instruments incorporate piping numbers as shown in Figure 4. Based on this, the piping numbers can be used to interconnect the entire process. Consequently, because almost process data documents involve piping numbers, this study will exploit process piping numbers to connect the main process components (equipment, valves, pipelines, devices, etc.).

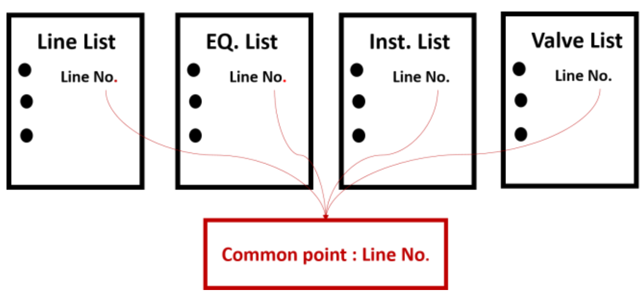


Figure 4. Line numbers as a common point

For the purpose of this study, the data mining will be suggested in three steps: data source (process design conditions), data extraction, and data presentation. Fortunately, we can save time by making use of SP P&ID®, since the data source and data extraction steps can be performed at nearly the same time within the program. Moreover, another critical benefit of the program is that the extraction EXCEL file has a flow directions for pipes under the two categories, "from" and "to" respectively, such as piping number for each equipment including the inlet or outlet pipes of the equipment. This useful information is collected once people properly create a P&ID figure with data.

Safeguards and recommended proper guidelines

Often, there is a tendency in the chemical industry to separate chemical and safety domains. However, process engineers should identify hazards to result in a safe design (including operating procedures) in process plants considering economic aspects. Some process engineers might overlook the safety considerations, believing that it is enough to follow their current project guidelines or industry standards. However, these rules or guidelines are not sufficient to minimize potential hazards. As many CSB incident investigation reports have found, there are also flaws in the recommended practices of the American Petroleum Institute (API), the American Society of Mechanical Engineers, and the National Fire Protection Association (NFPA) (Baybutt, 2016a), which are regarded as the most credible engineering guidelines. In case safer design schemes are not taken into account in initial design processes, numerous extra safety measures might be suggested during a HAZOP study, which is conducted near the middle of projects. In addition, they might struggle to find the safety issues from the HAZOP meeting, which could lead to unnecessary economic losses. Therefore, safety and process performances are unavoidably related.

Generic design solutions

According to CCPS (1998), safety system designs correspond to one of the following four categories: (1) inherently safer, (2) passive, (3) active, and (4) procedural. As mentioned in Section 0, proper safety system design is fundamental to reduce potential adverse events. Figure 5 presents an approximated comparison regarding expenses and the complexity of each safeguard. Namely, process engineers should seek a safer system by properly taking into account their own circumstances such as their cost benefits and regulations.

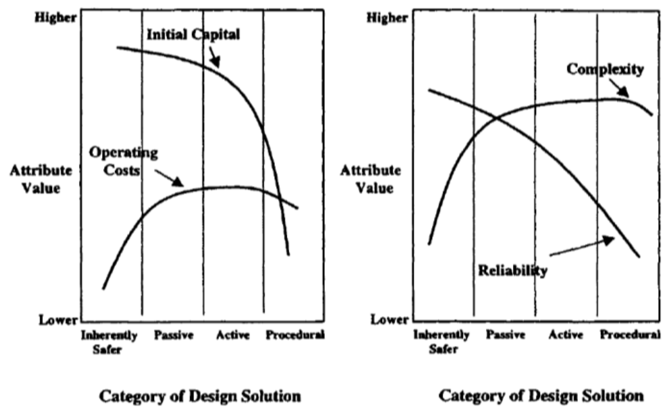


Figure 5. Comparison of Cost and Functional Attributes for Design Categories (CCPS, 2008)

Crowl and Louvar (2001) provide the definitions and examples of the four design solutions (Table2). There are often overlaps between the inherently safer and passive design solutions. Therefore, this study will integrate these criteria into one solution (CCPS, 1998) when the proper guidelines are outlined in the next section.

Table 2. The four design solutions

Design Solution	Definition	Example
Inherently Safer	To eliminate or mitigate hazards with less hazardous conditions or materials	Compatibility between heat exchanger and process fluid
Passive	To add safety features that do not require action from any devices. The associated devices are unrelated to process variables.	Double tube-shell construction
Active	To add active safety features depending on process variables	Installation of a PSV
Procedural	To require a person from performing an action to prevent potential incidents	Periodic sampling of a low-pressure fluid

Guidelines for design solutions

To date, many engineers have depended on personal experiences regarding safe design solutions. However, we should expect to have more reliable solutions using accumulated guidelines from the views of a myriad of process experts, rather than just relying on our unsupported intuition. Moreover, provided that the guidelines are clear to follow, the expected actions for process safety can be coherent across the process industry. This aspect can also influence young engineers to grasp process safety concepts without restrictive difficulty. CCPS (1998) employed the safety design solutions (inherently, passive, active, and procedural) for ten equipment types[4]. Since the guideline includes almost every component required in the chemical industry, it would be useful to apply safer designs to an actual process. Of course, these guidelines are merely one example. Depending on companies' experiences, more plant specific guidelines can be suggested or updated from the CCPS (1998) ones.

For example, level control of a vessel fails when the vessel sustains a low level, compared with the normal operation condition. Thus, according to CCPS (1998), we can determine the potential design solutions, as shown in given in Table 3, of sixty-one failure scenarios for a vessel. Firstly, we have to imagine a possible scenario for the failure mode. If a low level on a vessel is expected due to level control failure, we can elect the possible failure scenario such as Table 3. In other words, depending on the expected possible scenarios and deviations, process engineers can select one from among the sixty-one cases. Once engineers have envisioned a correct failure scenario, there are corresponding guidelines for designing a new process and for reviewing current process designs. In this study, the guidelines will serve to make a viable new semi-automated HAZOP.

Table 3. Example design solutions for vessel

Equipment :Vessel

No.	Operational Deviations	Failure Scenarios	Potential design solutions		
			Inherently Safer/Passive	Active	Procedural
45	Low Level	Level control failure	• Locate underflow nozzle to maintain a minimum liquid level in the vessel	• Low level alarm with shutoff preventing further liquid withdrawal from vessel via either pump shutdown or closure of a block valve	• Manual shutoff on low level indication

A new semi-automated hazard identification

As HAZOP is incapable of predicting an inherent failure mode of a process component, it is necessary to compensate the insufficient knowledge with FMECA. In this sense, this study integrates the two HAZID tools, HAZOP and FMECA; by making use of the system connectivity in Section 3.3, the new method enables the determination of possible causes and consequences in a system with the HAZOP perspective. Regarding the FMECA aspect, the tool weights the possible failure mode particularly that is associated with the environment of a system, inherent problems of each piece of equipment, and human errors.

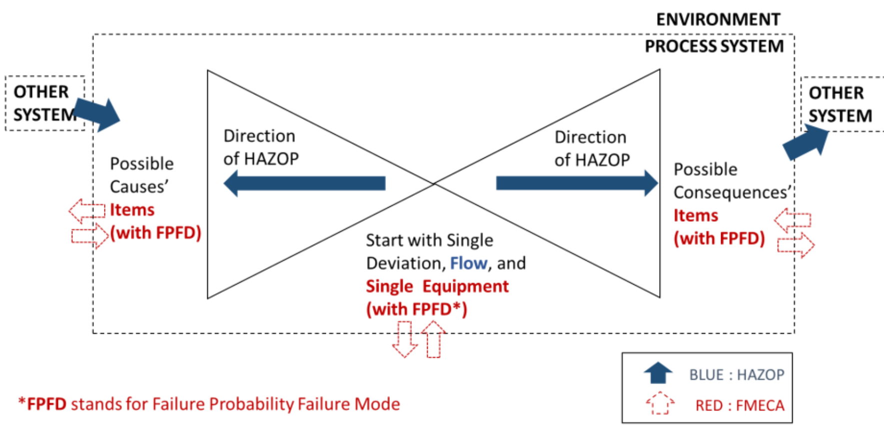


Figure 6. Working directions of new methodology:

[4] Vessel, reactors, mass transfer equipment, heat transfer equipment, dryers, fluid transfer equipment, solid-fluid separators, solids handling and processing equipment, fired equipment, and piping and piping components.

Figure 6 shows the overall workflow of the new methodology. The navy-blue and red-arrows present HAZOP and FMEA attributes, respectively. Regarding the HAZOP aspect, the significant characteristics of this method are to have a clear start point (*one reference equipment*) and a single guide parameter (*flow*) for possible causes. Following that one equipment is designated as a reference equipment, people can approach possible causes and consequences of a system only by considering *no, less, or more flow*. In order to support this task work effectively, this research will suggest *prepopulated* worksheets in the following sections. Meanwhile, FMECA has the function to review the failure modes of each piece of equipment, including their Failure Probability Failure Modes (FPFD) to approach a quantitative way. Ultimately, the new methodology utilizes the advantages of the two approaches to result in a more comprehensive view.

Failure scenarios associated with the HAZOP attribute:

Pre-requisite condition and aim

Based on the piping connectivity with fluid directions in Section 3.3, a pre-populated worksheet will be introduced to achieve a semi-automated analysis. For a reliable result, proper guidelines are needed to conduct a HAZOP study under leadership of a skilled HAZOP facilitator (MacGregor, 2013). Analogously, this proposed worksheet generates directions implicitly to engineers with respect to identification of possible causes and consequences. This aspect prompts a self-directed study and more discussions among engineers. Therefore, the following sections explain how to create the pre-populated worksheet.

Workflow with fluid directions

As mentioned above, the new method examines one parameter, flow, for possible causes. The strength of this approach is to use straightforward thinking. The main drawback in a HAZOP study is counterintuitive brainstorming. Theoretically, a HAZOP study examines all deviations combined with a process variable and guide word, as shown in Table 4. Based on the process parameter, the process continues to find all deviations, but this process raises issues. First, it is cumbersome to apply the combined deviations (typical deviations are shown in Table 4). Second, the required thinking in HAZOP is counterintuitive, because we have to find possible causes for a proposed deviation. That is, this step requires backward thinking (Baybutt, 2015a and MacGregor, 2013). Therefore, the way of thinking is not aligned with the common sense, which follows the same direction as fluid flow. In contrast, there will be more opportunities to review all the possibilities clearly, if the study is conducted in a natural sequence. For these reasons, this study seeks a more visible workflow along the fluid direction of a system.

Table 4. HAZOP deviation matrix

Guide words / Process Variables	**More**	**Less**	**None**	**Reverse**	**Part of**	**As well as**	**Other**
Flow	High flow	Low Flow	No Flow	Back Flow	Wrong concentration	Contaminants	Wrong material
Temperature	High Temperature	Low Temperature					
Pressure	High Pressure	Low Pressure					
Level	High Level	Low Level	No Level				

Adopted from Crawley & Tyler, 2015

Reasons for the fundamental variable, flow

There are two main reasons this study chooses flow as a fundamental parameter for a system. First, similar to pipelines, the flow has connections with other process variables, such as temperature, pressure, and level. In other words, flow is likely to propagate fault and to influence other process variables; the low flow of an inlet line brings about a low level for a vessel, or conversely the low flow of an outlet line can generate a high level for a vessel. Furthermore, it is convenient to have a simpler approach along the flow direction. In case of mixtures partial flow rates of components shall be tracked.

Another factor to consider with flow, fluid type

It is noted that every fluid has its own properties and may therefore exhibit different phenomena under the same conditions. For instance, at the same pressure and temperature, water and steam have different physical properties even though they have identical chemical structure. Assuming one inlet line for steam supply is blocked, by cooling the line might result in a vacuum state, which does not occur for in a water supply line. Consequently, it is also necessary to review potential scenarios regarding fluid type under operational conditions.

Prepopulated worksheets for HAZOP aspect

By making use of SQL language, this research proposes to create prepopulated worksheets along two approach methods, such as *path 1* and *path 2*, respectively. Microsoft SQL Server 2012® is applied to sort the possible cause items in the path 1 and path 2; the path 1 contains potential failure causes on inlet lines from a reference equipment, whereas the path 2 predicts potential causes on outlet line problems of the reference equipment. In accordance with the worksheets, we can perform a semi-automated

HAZOP grounded on the previous two prerequisites, only flow as a possible primary deviation and on recognizing fluid characteristics. Figure 7 represents how this research leads to HAZOP worksheets. In Figure 7, cells starting '#' mean that the cell will be filled with SQL coding to construct a prepopulated worksheet. Then, the yellow empty column under 'Check' must be reviewed by HAZID process engineers. In the spreadsheet, as expected, other variables such as level appear as a consequence. Once failure scenarios are selected, the corresponding safeguards can be suggested from accumulated experience (*e.g.*, CCPS, 1998)

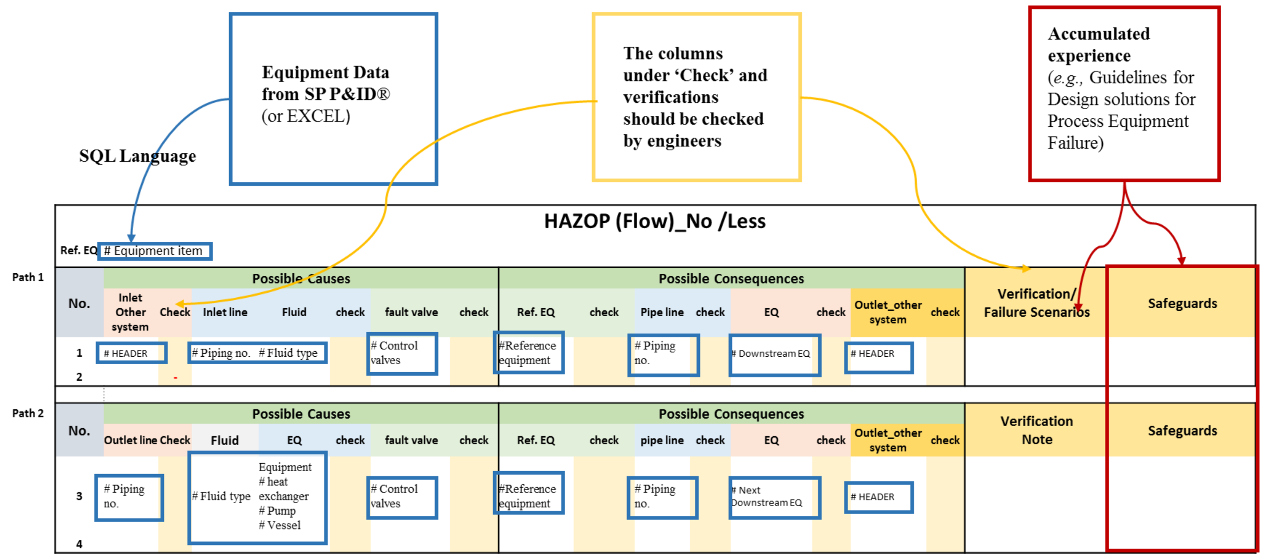


Figure 7. Sample guideline for HAZOP worksheet

Failure scenarios associated with the FMECA point

Regarding the failure mode of each item in the process industry, FMECA has been an important concept in the methodology for the causality approach. Because HAZOP does not take account of failure modes of an individual item, FMECA represents potential faults of each component in the process industry. Thus, including and utilizing the FMECA features, the new tool generates failure modes of each equipment. Failure rates or scenarios can be borrowed from authorized data sources (e.g., the CCPS, 1989 reliability handbook, or the databases of HSE, 2012 or OREDA, 2015). Other possible failure causes (such as environment and human error) must also be considered as well as how to reduce and identify them.

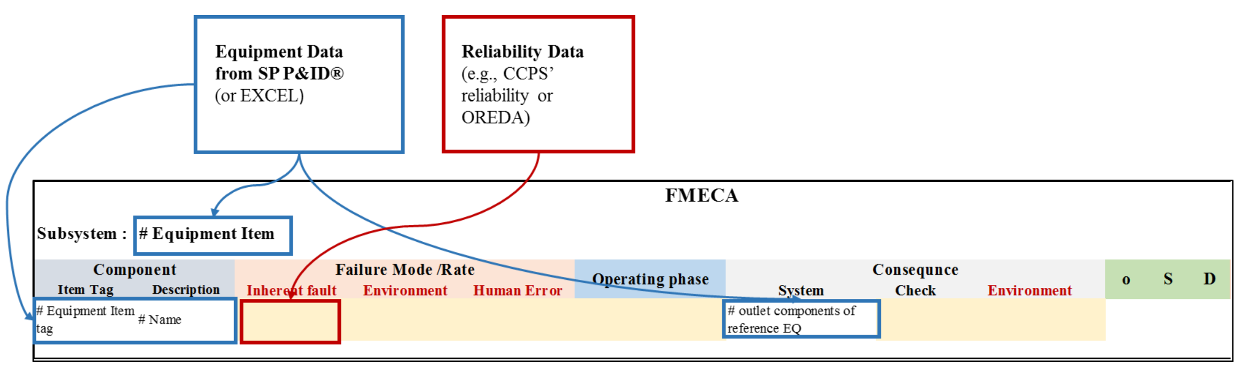


Figure 8. Sample guideline for FMECA worksheet

Overall workflow of new HAZID

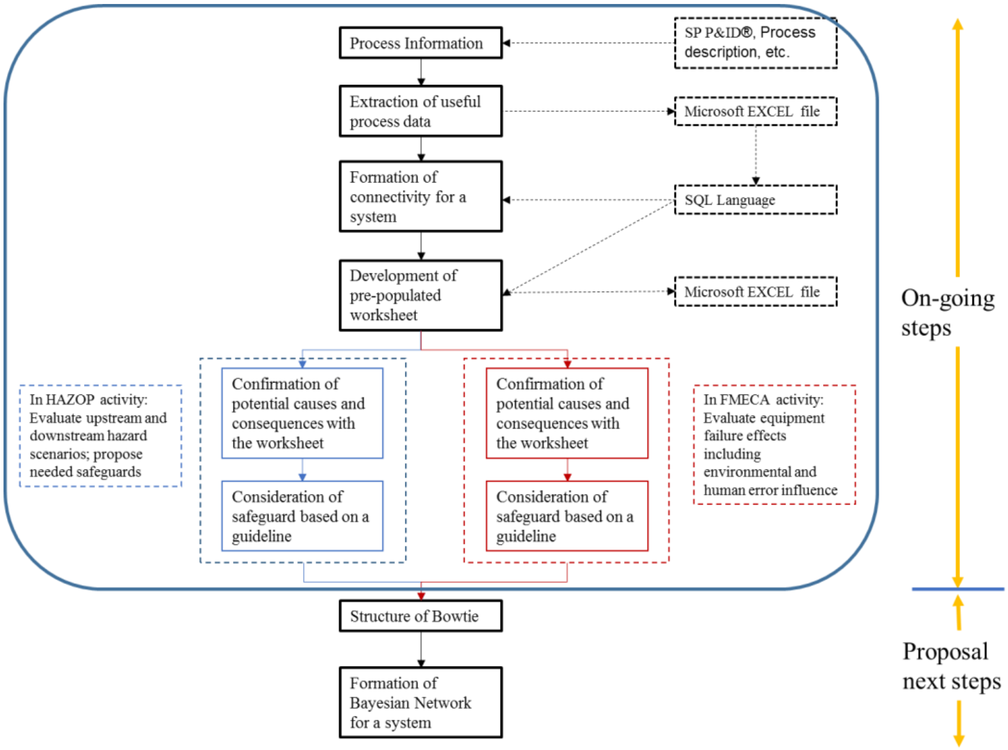


Figure 9. Workflow Diagram of New HAZID Tool

Figure 9 shows the overall workflow of the development of this new HAZID method with an on-going and a future part, while within the on-going part the actual work process is shown as followed here. Because of the several steps and the application of supporting technologies, it seems rather complex. The on-going part gets shape as shown in this paper; the proposed next steps will still take a further effort. However, the whole will result in a new semi-automated HAZID in which an HAZID-team will get the information in a more convenient and consistent way, so that the team can focus on the essentials of identifying and defining scenarios and does not have to bother about fuzzy information deficiencies. Once this development is completed, the achievement of safer process designs can be expected in a more time-efficient way.

A Brief Case Study

To confirm the methodology in Chapter 3, this research conducted a case study for a Boiler Feed Water (BFW) system including a de-aerator in Figure 10. At this time, only HAZOP aspects have mainly been performed. The current stage of the proposed concept of FMECA as described in Chapter 3, still requires more development to efficiently collect proper data of each item and produce failure scenarios. The relevant process description for this case study is omitted since the purpose of this case study is to show how to utilize SQL language.

Once we attain proper SQL language codes for HAZOP path 1 and path 2, those codes can be equally and readily applied to all equipment in the process system. As an example, Figure 11 and Figure 12 represent the SQL codes and their results for path 1 and path 2, respectively, regarding the heat exchanger in Figure 10. In addition, for the purpose of FMECA, Figure 13 shows how useful data can be extracted through the SQL language from an EXCEL file that was made by SP P&ID®. Finally, Figure 14 illustrates how HAZOP study can be performed with the antecedent outcomes from SQL codes. In comparison with its generic HAZOP study, the outcome of this research covers all scenarios, except those that are out of scope of this system and dealing with one manual valve. With respect to manual valves, moreover, one benefit of this novel method is to consider connections with other subsystems so that we can also predict disconnected conditions with them.

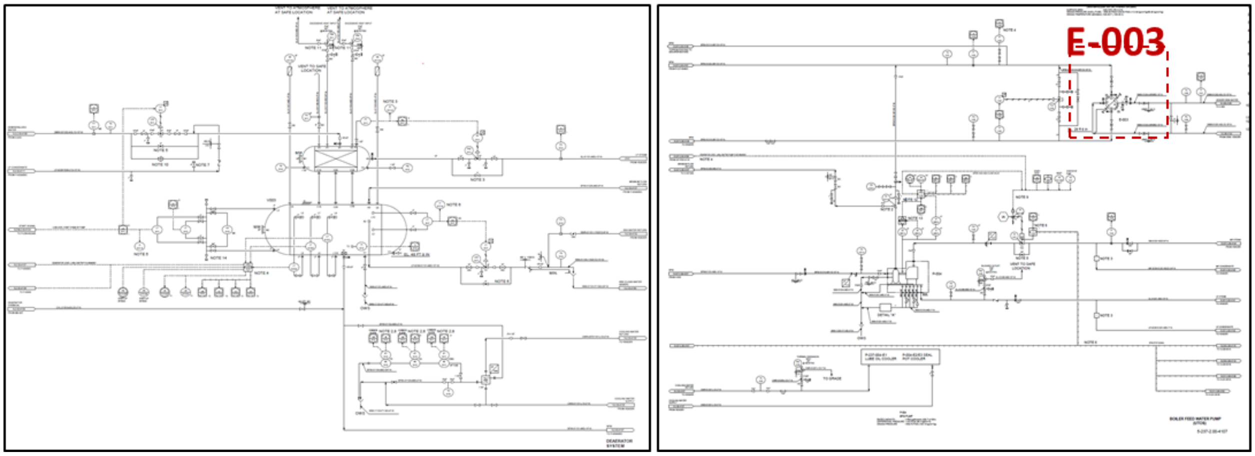


Figure 10. SP P&ID® figures for a case study (BFW supply system)

SQL Language

Example of SQL Language for HAZOP path 1

SQLQuery34.sql - P...ph_db (sunh9 (55))* | SQLQuery33.sql - P...ph_db (sunh9 (66))* | SQLQuery30.sql - P...ph_db (sunh9 (64))* | SQLQuery29.sql - P.

```sql
@V_EQUIPMENT VARCHAR(50);

SET @V_EQUIPMENT='E-003';

BEGIN
SELECT * FROM
(SELECT
(SELECT FROM_EQUIPMENT FROM dbo.GET_CONNECTION_OTHER_SYSTEMS_INLET(temp.from_equipment)) AS Inlet_Other_System,
temp.From_Equipment as 'Inlet Line',
left(temp.From_Equipment, charindex('-', temp.From_Equipment)-1) as 'Fluid',
pv.[Item Tag] as 'Fault Valve',
pv.[Instr Class] as 'Valve Type',
@v_equipment as 'Reference Equipment',
temp.to_equipment as 'Outlet Line',
(SELECT consequence FROM dbo.GET_CONNECTION_CONSEQUENCE(temp.to_equipment)) AS 'Consequence_Equipment1',
(SELECT to_equipment FROM dbo.GET_CONNECTION_OTHER_SYSTEMS_OUTLET(temp.to_equipment)) AS Outlet_Other_System
 FROM
    (SELECT c2.From_Equipment,
    c1.To_Equipment
    FROM  Connection$ c1,
          Connection$ c2
    WHERE c1.From_Equipment=@v_equipment
    and c2.To_Equipment=c1.From_Equipment)TEMP
LEFT OUTER JOIN Pipeline_Valve pv
 ON pv.[PipeRun Item Tag]= temp.from_Equipment
 AND pv.[Instr Class] IN ('Control valves and regulators','Relief devices'))TEMP2
WHERE (TEMP2.Inlet_Other_System is not null or [Fault Valve] is not null)
AND (TEMP2.Consequence_Equipment1 IS NOT NULL OR TEMP2.Outlet_Other_System IS NOT NULL);


END;
```

Enter equipment item tag.

SQL code

100 %

Results | Messages

	Inlet_Other_System	Inlet Line	Fluid	Fault Valve	Valve Type	Reference Equipment	Outlet Line	Consequence_Equipment1	Outlet_Other_System
1	NULL	BFW-237-01203-GR11D	BFW	237-FV-3121A	Control valves and regulators	E-003	BFW-237-01215-GR11D	NULL	BFW HEADER
2	NULL	BFW-237-01203-GR11D	BFW	237-FV-3121A	Control valves and regulators	E-003	DMW-237-01202-ASL1D	V-003	NULL
3	DEMI. Supply (HEADER)	DMW-237-01203-GRW5D	DMW	NULL	NULL	E-003	BFW-237-01215-GR11D	NULL	BFW HEADER
4	DEMI. Supply (HEADER)	DMW-237-01203-GRW5D	DMW	NULL	NULL	E-003	DMW-237-01202-ASL1D	V-003	NULL
5	NULL	BFW-237-01214-GR11D	BFW	237-TCV-3123	Control valves and regulators	E-003	BFW-237-01215-GR11D	NULL	BFW HEADER
6	NULL	BFW-237-01214-GR11D	BFW	237-TCV-3123	Control valves and regulators	E-003	DMW-237-01202-ASL1D	V-003	NULL

SQL results

Figure 11. SQL language for HAZOP path 1 and its result

As an example, the heat exchanger E-003 in Figure 10 was selected. Of course, if the item tag is changed, we shall get different corresponding results. Once we input an equipment item tag among the various tags in the system concerned, we can see the connection of the selected equipment upstream and downstream to the next main component readily, which is the basis for creating a prepopulated work sheet such as presented in Figure 14.

Example of SQL Language for HAZOP path 2

SQLQuery34.sql - P...ph_db (sunh9 (55))* SQLQuery33.sql - P...ph_db (sunh9 (66))* SQLQuery30.sql - P...ph_db (sunh9 (64))* SQLQuery29.sql - P...

```sql
@V_EQUIPMENT VARCHAR(50);

SET @V_EQUIPMENT= 'E-003';

BEGIN

   SELECT * FROM
   (SELECT temp.To_Equipment AS 'Outlet line',
          left(temp.To_Equipment, charindex('-', temp.To_Equipment)-1) as 'Fluid',
          (SELECT consequence FROM dbo.GET_CONNECTION_CONSEQUENCE(temp.To_Equipment)) AS 'Equipment',
          temp.[Item Tag] AS 'Fault Valve',
          temp.[Instr Class] AS 'Valve type',
          temp.From_Equipment AS 'Ref. Equipment',
          c2.to_equipment as 'Outlet Piping',
          (SELECT consequence FROM dbo.GET_CONNECTION_CONSEQUENCE(c2.To_Equipment)) AS 'Consequence Equipment',
          (SELECT to_equipment FROM dbo.GET_CONNECTION_OTHER_SYSTEMS_OUTLET(c2.To_Equipment)) AS 'Other System'
   FROM
      (SELECT c1.From_Equipment,
              c1.To_Equipment,
              pv.[Item Tag],
              pv.[Instr Class],
              pv.fluid,
              (SELECT consequence FROM dbo.GET_CONNECTION_CONSEQUENCE(C1.To_Equipment)) AS 'Equipment'
      FROM Connection$ c1
      LEFT OUTER JOIN Pipeline_Valve pv
      ON pv.[PipeRun Item Tag]= c1.to_equipment
      AND pv.[Instr Class] IN ('Control valves and regulators','Relief devices')
      WHERE c1.From_Equipment=@V_EQUIPMENT)TEMP
   LEFT OUTER JOIN Connection$ c2
   ON c2.From_Equipment= Temp.Equipment)TEMP2
   WHERE (TEMP2.[Equipment] IS NOT NULL OR TEMP2.[Fault Valve] IS NOT NULL);

END;
```

Enter equipment item.

100 %

Results | Messages

	Outlet line	Fluid	Equipment	Fault Valve	Valve type	Ref. Equipment	Outlet Piping	Consequence Equipment	Other System
1	DMW-237-01202-ASL1D	DMW	V-003	237-LCV-3111	Control valves and regulators	E-003	BFW-237-01101-A6D	P-004	NULL
2	DMW-237-01202-ASL1D	DMW	V-003	237-LCV-3111	Control valves and regulators	E-003	LP-SCW-237-01101-A6D	NULL	WW (Clean Water Sewer) Header
3	DMW-237-01202-ASL1D	DMW	V-003	237-LCV-3111	Control valves and regulators	E-003	SL-237-01102-A6D	NULL	NULL
4	DMW-237-01202-ASL1D	DMW	V-003	237-LCV-3111	Control valves and regulators	E-003	SL-237-01104-A6D	NULL	NULL

Figure 12. SQL language for HAZOP path2 and its result

As before in Figure 11, Figure 12 represents how to obtain the HAZOP path 2 for the heat exchanger, E-003.

Example of SQL Language for FMEA

SQLQuery34.sql - P...ph_db (sunh9 (55))* SQLQuery33.sql - P...ph_db (sunh9 (66))* SQLQuery30.sql - P...ph_db (sunh9 (64))* SQLQuery29.sql - P...ph_db (sunh9

```
select [Item Tag],
Name,
Description,
[Design Max Press],
[Design Min Press],
[Design Max Temp],
[Differential Press],
[Rated Capacity],
[Design Duty],
[MOC Class],
[Insul Purpose]
from fmea_eq;
```

100 %

Results Messages

	Item Tag	Name	Description	Design Max Press	Design Min Press	Design Max Temp	Differential Press	Rated Capacity	Design Duty	MOC Class	Insul Purpose
1	V-003	DEAERATOR	VESSEL	90PSIG	FV	620F	NULL	NULL	NULL	C.S	Ih
2	P-004	BFW PUMP	PUMP	1538.7 PSIG	NULL	281.3 F	1143.7PSI	1156.6gallon/min	NULL	C.S	Ih
3	P-004-T	NULL	STEAM TURBINE	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
4	E-003	DEMINERALIZER WATER PREHEATER(BEM)	SHELL&TUBE HEAT EXCHANGER	Shell: 1620 PSIG; Tube: 1230 PSIG	Shell: FV; Tube: FV	Shell:320F; Tube: 248F	NULL	NULL	18.68 MMBTU/hr	C.S	Ih

Figure 13. SQL language for FMECA (extraction of data of interest)

Of the numerous data for process equipment in the EXCEL file of SP P&ID®, Figure 13 represents how for FMECA for each equipment useful data can be extracted. At this stage, primary design values are retrieved such as design pressures, temperatures, and design duty, etc., because based on this information HAZID-engineers will determine whether proper designs have been proposed.

Example of worksheets for HAZOP path 1 and 2

HAZOP (Flow)_No /Less

Ref. EQ E-003

Path 1

No.	Possible Causes: Inlet Other system	Check	Inlet line	Fluid	check	fault valve	check	Possible Consequences: Ref. EQ	check	Pipe line	check	EQ	check	Outlet_other system	check	Verification/ Failure Scenarios	Safeguards 1	Safeguards 2
1	NULL	-	BFW-237-01203-GR11D	BFW	-	237-FV-3121A	None	E-003	None	BFW-237-01215-GR11D	None	NULL	-	BFW HEADER	None	Assumption _Because of ARV's capacity, the chance of the failure of this ARV is very less regarding blocking its outlet line	-	-
2	NULL	-	BFW-237-01203-GR11D	BFW	-	237-FV-3121A	None	E-003	None	DMW-237-01202-ASL1D	None	V-003	None	NULL	-	Assumption _Because of ARV's capacity, the chance of the failure of this ARV is very less regarding blocking its outlet line	-	-
3	DEMI. Supply (HEADER)	NF (LF)	DMW-237-01203-GRW5D	DMW	NF (LF)	NULL	-	E-003	NF (LF)_ cold (tube)	BFW-237-01215-GR11D	None	NULL	-	BFW HEADER	None	-	-	
4	DEMI. Supply (HEADER)	NF (LF)	DMW-237-01203-GRW5D	DMW	NF (LF)	NULL	-	E-003	NF (LF)_ cold (tube)	DMW-237-01202-ASL1D	NF (LF)	V-003	LL	NULL	-	1. V-003 : Low level (LL)_ (T3/No.41) Level control failure	Refer to No.1-1 (HAZOP result of vessel)	
5	NULL	-	BFW-237-01214-GR11D	BFW	NF (LF)	237-TCV-3123	NF (LF)	E-003	LP	BFW-237-01215-GR11D	LP	NULL	-	BFW HEADER	LP	1. E-003 : Low Pressure (LP) Adopted from (T3/No.22) Under pressure or Vacuum : Uncontrolled condensation/absorption of vapor phase component_ Active safeguards were deleted	Regarding E-003 1-1) Vessel design to accommodate max. vacuum (full vacuum rating) : **F.V** 1-2) Insulation :**IH** 1-3) Open vent : **Done** 3) Operating procedure for monitoring temperature and addition rate of materials : **TIC-3123(L)**	Regardgin BFW HEADER The supply header design to accommodate max. vaccum (Full vacuum rating)
6	NULL	-	BFW-237-01214-GR11D	BFW	NF (LF)	237-TCV-3123	NF (LF)	E-003	NF (LF)_ Hot (Shell)	DMW-237-01202-ASL1D	1. LP 2. LT	V-003	1. LP 2. LT	NULL	-	1. V-003: Low Pressure (LP) refer to HAZOP result for Vessel No.3 2. V-003 : Low Temperature (LT) (T3/No.34) Low temperature material fed to vessel	**Regarding V-003** 1) Vessel design to accommodate minimum expected feed temperature 2-1) Low temperature alarm and feed isolation interlock 2-2) Low temperature alarm activates external heating 3) Instructions to isolate feed on low temperature indication	-

Path 2

No.	Possible Causes: Outlet line	Check	Fluid	EQ	check	fault valve	check	Possible Consequences: Ref. EQ	check	pipe line	check	EQ	check	Outlet_other system	check	Verification Note	Safeguards 1	Safeguards 2
7	DMW-237-01202-ASL1D	NF (LF)	DMW	V-003	None	237-LCV-3111	NF (LF)	E-003	None	BFW-237-01101-A6D	-	P-004	-	NULL	-	-		
8	DMW-237-01202-ASL1D	NF (LF)	DMW	V-003	None	237-LCV-3111	NF (LF)	E-003	None	LP-SCW-237-01101-A6D	-	NULL	-	WW (Clean Water Sewer) Header	None	-		

Figure 14. Performed HAZOP study following SQL coding, extraction and component linking.

The abbreviations in Figure 14 are NF (No Flow), LF (Less Flow), BFW (Boiler Feed Water), and DMW (Demineralized Water).

Conclusions

By making use of Smart Plant Piping and Instrument Diagram® (SP P&ID®), Microsoft EXCEL, and SQL (Structured Query Language) tools, this research will represent a novel way of increasing the completeness and effort efficiency of HAZID. Rather than examining each component separately, the combination of components to a functioning part of plant enables people to perceive the 'bigger picture'. Thus, this research proposes a new method for deriving this overall insight both for an individual and for a team point of view. To achieve a comprehensive understanding and hazard identification by assuming fault/deviation, it is critical to follow proper connections between components of a system in fluid flow direction, which can be extracted from the SP P&ID®. Through these links, HAZOP and FMECA may be performed semi-automatically, while retaining 'human-in-the-loop' to overcome the current limitations of each type of analysis. The new method will enable determination of possible causes and consequences in a system from the HAZOP functioning perspective including operational errors, whereas FMECA will check effects of a system's possible failure modes, including those by its environment, inherent problems of each piece of equipment by loading and material wear, and human errors occurring in construction, operation and maintenance. Based on the current stage (on-going steps) in Figure 9, this research can be taken further by combining identified scenarios to clusters in a Bowtie structure and conveying Bowtie to Bayesian networks. These next steps of the proposal can produce visual causal relationships and quantification to diagnose effectively possible root causes according to their relative probabilities. In addition, this study can be extended to abnormal, start-up, turn-around, or batch operation conditions, because the current case study was performed mainly for normal steady-state process conditions.

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