

**CHE 41100**

**Identification of Gaps in Inherently Safer Design Analysis  
Methodologies and Possible Solutions**

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## **Executive Summary**

This report provides an analysis and evaluation of the current knowledge compiled on Inherently Safer Design (ISD) analysis methodologies and the gaps that exist within each identified attribute that is believed to be part of the model ISD process hazard analysis. This was achieved through the abstract thinking of what characteristics of ISD can be improved in order to act as a viable option for standard safety procedure in industry. The study began through the generation of a list of attributes believed to be directly related to a model PHA method for ISD. The attributes are as follows: (1) complete, (2) consistent, (3) comparable, (4) technically sound, (5) practical, (6) efficient, (7) cost effective, (8) rigorous, and (9) scalable. Subsequently, the existing gaps and limitations for each attribute were identified. The two main categories of solution approaches toward the gaps included qualitative industry methods, along with quantitative indexing methods. A compilation of possible solution approaches for both categories was tabulated using articles written by academics, and suggestions of experienced industry leaders. Through the analysis of both methods in the study, it was shown that ISD, accompanied by its principles and strategies invoke the need of abstract thinking, technical knowledge, and an overall awareness of its philosophy. As a summary, the ideal approach to resolving the existing gaps of an ISD safety procedure requires a method that incorporates qualitative and quantitative approaches. It is only through the succinct combination of both methods, that ISD methodology will possess the nine proposed attributes. However, due to the novelty of ISD as a practical means of PHA, there is currently a limited adoption of ISD in industry. The first step towards possible improvements towards building the ideal ISD methodology will be to spread awareness on the potential of ISD. Through this, there exists a possible increase of case studies that deal with economic benefits, increase of willingness and desire to change, and also the improvement of knowledge about ISD amongst researchers and engineers.

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## Introduction

Inherently Safer Design (ISD) is a chemical process safety philosophy that is typically applied to the overall design and operational life cycle of a chemical process in order to reduce the hazards of a process. It is applicable to manufacturing, transportation, storage, usage, disposal, and all other forms of operations in the chemical industry. Furthermore, ISD focuses on the four main strategies, including: 1) Minimization; reducing the quantities or types of chemicals for the reduction or elimination of a hazard, 2) Substitution; replacing chemicals or equipment with less hazardous ones, 3) Simplification; reducing human error by making a design less complex, and 4) Moderation; reducing the intensity of the processing variables such as pressure or temperature. In short, ISD focuses more on reducing the hazards of the process, rather than living with the hazard and adding layers of protection to mitigate the risk.

For the most part, ISD has been a concept and only casually used by industry rather than a formally adopted and frequently used structured method. The possible reasons for this are lack of appreciation of the benefits, perception it is only a concept to be used early in a process's lifecycle, or lack of adoption of a consensus on ways in which the concept of ISD can be formalized into a useful and routine methodology. This presents a wide variety of opportunities to approach process safety and this relatively novel concept and can potentially become a standard operating procedure for process plants worldwide. However, there is a misunderstanding of ISD hazards analysis methodologies, and these possible gaps need to be addressed before this concept is widely adopted by professionals in the industry. At this time, ISD is considered a conceptual, perhaps impractical philosophy rather than a useful method that should be frequently used. Most practitioners in industry only infrequently analyze hazards by ISD strategies due to the perceived subjectivity that is instilled within it. Due to this, ISD is either ignored or acts merely as a trivial part of standard safety procedure in process plants.

However, there are also those who believe in the potential of ISD, popular figures to note are Trevor Kletz<sup>15</sup> and Dennis Hendershot<sup>12</sup>, who have contributed a great deal of thought into the concept by providing anecdotal experiences regarding the potential of ISD through their written work and research. Moreover, there are those who have attempted to quantify inherent safety through means of indices, notable figures are Anna Marie Heikkilä<sup>10</sup>, Paul Amyotte<sup>13</sup>, David Edwards<sup>6</sup> and many more who will be mentioned in this report. Options that have been developed include conducting an ISD study using techniques similar to Process Hazard Analysis (PHA) methods and those methodologies that are composite indices and produce a relative risk value for comparison of designs.

## Objective

The objective of this research was to improve the use and quality of ISD methodologies in industry by identifying the key attributes of a model approach to using ISD as a formal hazards analysis methodology to identify gaps with current techniques, and to make recommendation for further consideration. Through the conclusions that are drawn from this work, an approach to identify hazards using ISD principles can be improved. This research acts as a stepping-stone for future research and improvement of the proposed solutions of the attribute gaps, with a goal of enhancing the use of ISD as a common method in industry.

## Methodology

For a chemical process to be considered “inherently safer”, it should be analyzed by a methodology that includes the four main strategies of ISD: minimization, substitution, simplification, and moderation. Any possible application of these principles would make for at least one hazard in the process to be inherently safer than before given practical implementation of an alternative design or operation.

An issue is how to do this and what constitutes a complete, thorough and repeatable method. In order to gain better insight into possibilities for improvement of ISD methods, a list of attributes of an ideal methodology were brainstormed to set criteria by which to judge existing methods, to identify gaps, and to recommend improvements. The criteria selected were: (1) complete, (2) consistent, (3) comparable, (4) technically sound, (5) practical, (6) efficient, (7) cost effective, (8) rigorous, and (9) scalable. They are covered with more depth in the Analysis section, as well as a detailed table in the appendix. These attributes, along with their gaps and solutions would then be expected to act as a contribution to an enhanced methodological approach to ISD, potentially edging it towards common usage in industry. Both qualitative and quantitative ISD methods used in industry were evaluated against the nine attributes, resulting in the identification of strengths and weaknesses of the ISD method. Subsequently, conclusions of solutions for each attribute were drawn based on the knowledge gathered from both ISD methods commonly used in industry as well as index methods proposed by researchers.

The Appendix was constructed to concisely summarize the ideas and concepts gathered through this study. Individual columns were included to thoroughly explain the objectives, gaps, industry approach methods, and conclusions of each proposed attribute. Based on the attribute, an objective is defined, followed by a list of possible gaps that require solutions. Finally, existing methods from two industry approaches are evaluated to reconcile possible solutions to the gaps.

## Industry Approach to ISD Analysis

In the Methodology section, it was noted that industry had two main ISD methods, qualitative and semi quantitative. The 2019 CCPS ISD Guidelines<sup>3</sup> utilizes qualitative PHA methods such as a checklist that involves the integration of ISD concepts within a HAZOP (Hazard and Operability Study), a typical PHA checklist that focuses exclusively on inherent safety at every subsystem of a process, and lastly an approach where ISD is brainstormed at each subsystem to address each hazard and then opportunities for applying ISD strategies are discussed. These methods are undoubtedly rigorous in a sense that the analysts are forced to keep inherent safety in mind while conducting the analysis. However, these methods may lack completeness for a number of reasons if not thoroughly planned and executed with a sufficient framework for the methods. For example, there could be hazards that are absent from checklists making that method limited. There could be a lack of understanding of options for applying ISD strategies due to insufficient knowledge base on inherently safer designs. Some methods are simply inefficient and take an extensive amount of time to complete, making them less practical and limiting their use.

Moreover, regarding quantitative measures for inherent safety, several index methods have been proposed to quantify inherent safety. Notable examples of these indices are as follows: Integrated inherent safety index (IS2I)<sup>13</sup>, Process and hazard control index (PHCI)<sup>13</sup>, Equipment process route index (EPRI)<sup>1</sup>, Conventional safety cost index (CSCI)<sup>13</sup>, and so on. A few examples include the following: The I2SI index involves the measurement of both potential safety and hazards to devise a quantification of inherent

safety. This can possibly be a solution to the completeness and consistency attributes. However, it is not necessarily effective in solving the gaps present in the scalability attribute. Additionally, EPRI incorporates all chemical, process, and equipment aspects into a single quantifiable value. This allows the index to act as a solution to the completeness, comparability, technically sound and practicality attribute gaps. Methods such as indices may try to derive a singular value that may not be fully appreciated as giving practical advice or is rarely used for existing plants.

As a whole, it can be agreed that both quantitative and qualitative methods have their merits and drawbacks. However, a combination between the two could aid in solving many of the limitations that ISD as a PHA faces.

## **Analysis**

ISDs are primarily based on an informed decision-making process because a recommended option may be inherently safer in one case, but inherently less safe in another case. Therefore, the decision process must consider the overall process cycle, followed by a spectrum of possible hazards and risks, as well as the potential transfer of risks from one node to another due to the changes made. Technical and economic factors need to be considered as well. Due to all the subjectivity involved with ISD, a list of attributes was generated in hope to potentially fill the gaps that exist and develop a methodology that is more straightforward and hopefully widely adapted.

As stated in the previous section, the industry method includes both qualitative and quantitative ISD approaches. An ideal situation would be if both those categories can be merged in order to eliminate the gaps that exist for ISD as a model PHA method. For this methodology to reach fruition and be accepted by industry, a combination of qualitative and quantitative solutions for the nine proposed attributes needs to be devised. A brief description of each attribute is as follows:

- (1) Completeness: Ensures that all hazards are identified and ISD options considered.
- (2) Consistency: Ensures that ISD methodology can be applied in the same manner against different and similar processes.
- (3) Comparable: Ensures that ISD methodology can provide repeatable results against different and similar processes as a standard safety operating procedure.
- (4) Technical soundness: Ensures that the required depth of technical analysis of hazards is addressed by the ISD methodology and it gives reliable results.
- (5) Practicality: Ensures that ISD methodology and recommendations are based on readily available technology, knowledge of the process plant, is not too difficult to understand and use, and gives practical output.
- (6) Efficiency: Ensures the ISD analysis requires an acceptable amount of time to apply and is worth the effort employed.
- (7) Cost effectiveness: Ensures that ISD analysis recommendations are economically sound within the constraints of the operation.
- (8) Rigor: Ensures that ISD concepts and methodologies exist as an accepted “state of mind” for all in the chain of command, which encourages an overall “inherently safer” work culture and environment, and that it can be adopted as a common rigorous method across an enterprise.
- (9) Scalability: Ensures that ISD methodology is applicable for overall processes of different scale and complexity.

### Attribute 1: Completeness of methodology

To achieve full completeness of a methodology would be virtually impossible since there exists a barrier for human thinking, while existing gaps are unexplored. However, there are steps that can be taken to achieve a methodology with improved overall completeness. A process safety analysis method is typically regarded as incomplete if the analyst is unable to effectively identify the hazards of a process, along with its significance. Therefore, it is crucial for employees to have a better understanding of ISD strategies and how they eliminate or reduce hazards to maximize the damage mitigation of incidents. Through the spread of ISD knowledge, various approaches to the relevant technology in a process would be discovered by operators, allowing room for improvement in ISD as a PHA method.

Additionally, checklists are commonly used methods in industry that offer assurance of completeness. However, checklists are non-universal, leading to its ineffectiveness throughout different processes. It is only through additional analysis of the process by operators with experience will it be possible for unrecognized hazards to be identified.

### Attribute 2: Repeatable / Consistent methodology

The repeatability or consistency of the methodology is self-explanatory in a sense that it should be capable of being applied throughout all situations, despite the difference in complexity, process, chemicals, or equipment. However, due to the variation of designs and equipment through processes, it is challenging to apply ISD methodologies consistently. Different process plants tend to have different constraints on the operating conditions of equipment such as reactors, distillation columns, absorbers and so forth. Differences in safety tolerance and economic budget can also affect the repeatability of the ISD methodology. As a compromise, some index methods can be used to calculate and quantify inherent safety, while also incorporating factors such as cost-efficiency. Examples of index methods are covered in detail in the Appendix.

### Attribute 3: Comparable within plant and industry

ISD methodology as a PHA method is commonly disregarded due to its novelty. When compared to popular procedures such as HAZOP studies and safety checklists, professionals might find it challenging to begin to adopt ISD. This is an issue because there is no defined method to quantify the inherent safety and its value. A possible approach would be to identify the hazards and propose solutions based on the four ISD strategies. As an example, a comparison between existing solutions and ISD recommendations would broaden the field for analysts and provide more insight towards potential changes that can be made to prevent incidents for occurring, rather than focusing on the incident response. The specific measures that can be taken to improve ISD methodologies are listed in the Appendix.

### Attribute 4: Technically sound implementation

Recommendations from ISD methodologies might be impossible, considering the currently available technology if the process plant is not up to par with the technological changes recommended. These issues are mostly solved through internal improvements that can be made by the plant that intends to apply the ISD methodology, whether it be technological advancements or administrative changes. There is also a possibility that index methods can be utilized as supporting tools to resolve the gaps that arise for the attribute. Also, this attribute is dependent on the thoroughness of the analysis approach, along

with the proper application of the method executed by a knowledgeable and experienced team of various disciplines. Details are elaborated further in the Appendix.

#### Attribute 5: Practical / Feasible application of methodology

For ISD to become a model PHA method in industry, it is crucial that the analysis is practical to implement. This heavily weighs on the complexity of the process in question and is dependent on the process nodes defined. Detailed explanations along with an example involving the EPRI index method can be found in the Appendix.

Additionally, the recommendations given by the ISD analysis must be practical to implement. Due to the nature of ISD strategies, the potential options available are limited to the knowledge on the chemicals, equipment, and operating conditions of the process involved. For example, a specific process might involve hazardous materials and operate at dangerous conditions. However, if there is no knowledge or data on possible alternative materials or reactor types, it would be impossible to provide a practical recommendation. The more practical outcomes from ISD studies the more likely there will be further appreciation of its value and encourage industry use.

#### Attribute 6: Efficient implementation of analysis

The efficiency of the ISD methodology is important because a safety analysis that can be implemented in short periods of time will improve the overall productivity of the analysis. This could prompt an increase in industry usage of ISD in their safety checkups. However, people tend to stick or return to traditional methods due to their attractive familiarity. For example, HAZOP studies may take weeks to months of repetitive evaluations on a pre-written checklist, while not providing proportional useful recommendations for safety improvement. If ISD was incorporated into the HAZOP approach it may add some modest additional effort but the gains in insight with the ISD perspective would be great. If there is enforcement of ISD as an integral part of the safety culture, then a “state of mind” would allow for a more common use of the approach to all situations. Through the implementation of ISD as a philosophy, employees will focus on the mitigation or elimination of hazards where possible instead of layers of protection. This means that hazards analysis procedures do not necessarily need to take place only for inherent safety to be applied, ultimately making the ISD methodology extremely efficient.

#### Attribute 7: Analysis produced cost effective results that include possible options

There are many aspects to cost and it acts as a defining factor for all firms. Naturally, a method that produces the most cost-effective solution while attaining success in improving the safety of a process is ideal. However, that is not always the case, there might require a certain sacrifice of one to obtain more of the other. Therefore, a common ground can be reached through the combinations of qualitative and quantitative ISD measures, which allows for the process to be run at reasonable cost at a relatively safer state. A simple example might include the utilization of the Dow and Mond Fire and Explosion Indices to calculate the risk at early stage of a process life cycle and determine the possible economic loss that is present, then comparing them to the cost of implementing the ISD recommendations. Further elaboration on additional index methods and examples are included in the Appendix.

#### Attribute 8: Rigorous implementation of analysis

Applying rigor to the ISD methodology would allow for an increased reliability in the method, providing a means of adoption by industry. However, there always exist minute issues that tend to be ignored within the process due to its apparent insignificance. It is possible for employees or even analysts to take certain unusual scenarios too casually and decide to omit them from the ISD PHA to make things “simpler.” This simple lack of rigor typically results in an increased overall risk in a process. Therefore, it is crucial that the ISD methodology is implemented with rigor, along with defined constraints. Heikkilä has proposed an index method that assists in approaching a rigorous ISD analysis procedure, that is explained in the Appendix. On a side note, an emphasis on ISD as part of safety culture would allow for widespread awareness of its potential, leading to the development of a standardized safety procedure that is utilized throughout process plants.

#### Attribute 9: Scalable within industry

Given the diversity of designs in the process industries, the ISD methodology needs to be applicable to any size or type of process. However, it is challenging to address every factor that can be involved within the calculations or measurements of inherent safety. What would apply to a small-scale process would differ from that of a large-scale process. Fundamentally, the simplicity of considering the four strategies for each hazard is a universal tool and widely applicable and scalable. Risk matrices may be a method to kickstart the approach towards a solution, alongside some index methods that retain their validity through changes in scale. Further research and improved technology would allow for improved solutions of this attribute.

### **Conclusion**

ISD is a relatively novel concept to be adopted within industry, which explains why there exists the need for a sound, accepted methodology for the practice of ISD analysis as a standard safety procedure. Given the work done throughout this research, nine total attributes of a model PHA method with ISD principles were identified as: (1) complete, (2) consistent, (3) comparable, (4) technically sound, (5) practical, (6) efficient, (7) cost effective, (8) rigorous, and (9) scalable. Through analysis, possible gaps were derived from these attributes, followed by their respective solutions that would aid in ensuring the model PHA method using ISD concepts. Through the evaluation of present industry approaches to applied ISD analysis, there still exist factors that can be identified to improve the solutions for the gaps proposed in this research. Due to the subjective nature of ISD, it is challenging to ensure that both quantitative and qualitative methods are incorporated to achieve an ideal ISD methodology. A subjective approach such as a HAZOP-style checklist may not be rigorous enough and is not necessarily repeatable for different processes, whereas a specified index method such as the IS2I<sup>13</sup> or EPRI<sup>1</sup> may be impractical given the nature of the high-level input and output of the tools doesn't address every hazard. Nonetheless, while there is some rigor of using a checklist on each node, there is a possibility of decreased efficiency. Checklists becomes only marginally useful because it doesn't strive for new ideas. The relation of cost-effectiveness and inherent safety needs to be clarified to obtain a common ground, and ultimately provide a win-win situation to maintain economic, environmental and public balance.

### **Recommendations**

The research gathered throughout the course of this study is valuable and acts as a stepping-stone towards the standardization of ISD methodologies as a model PHA method. However, there still exists areas of required further work to be done to solidify ISD's place in industry. From this study, it was established that neither the qualitative and subjective methods, nor the quantitative, indexing methods were able to satisfy all the criteria for resolving the existing gaps for each attribute. This is because the definition of inherent safety is abstract and will be defined differently by different professionals. In addition, as stated at the beginning, ISD is still a rather novel concept and it requires time to spread the philosophy behind its strategies and principles. Additional work on a thorough, universal node and hazard identification method that is time-efficient can be the first step towards the development of an early version of an ideal PHA method through ISD. Another suggestion for future measures is to hold an official panel of experts in chemical safety to either develop an agreed upon index method or to form a consensus on an existing index method. In the years to come, an ideal situation would be for ISD to have attained a spot in effectively creating relatively safer working environments for all professionals in industry.

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Appendix - Summary of attributes of a model PHA method for ISD

Attribute	Objective	Possible Gaps	CCPS – Guidelines for ISD <sup>3</sup>	Index Methods	Conclusions
1. Completeness	<p>Identify all possible hazards that are present in entire process and include and properly evaluate all hazards of relevance and significance. Analysis by nodes are a good method of doing this since it isolates sections of the process at a time thereby focusing the analyst on a manageable area of process. This is more orderly, taking one step at a time in the flow of the process, and it is isolating process intention (process parameters, technology, and physical equipment). However, it may be impossible to achieve completeness since is a constant learning process and other constraints.</p> <p>Idea: Include other factors that affect decision in change.</p>	<p>There is no rule on how to select nodes.</p> <p>Subjective how to approach the ISD analysis other than the use of 4 strategies.</p> <p>Lack of rigor on conducting a study.</p> <p>No measure of how inherently safe a process must be.</p> <p>No criterion for feasibility of an ISD idea.</p> <p>Lack of knowledge of options for inherently safer technologies or designs</p>	<p>(+) Method is independent and acts as a good measure for keeping track of what can be done.</p> <p>(+/-) Checklist – provides some structure for more ‘complete’ analyses. However, checklists may be limited so they are not a good assurance of completeness since they are not specific to the hazards of the process, nor are they always relevant to questions.</p>	<p>1. A checklist of the attributes listed on here can assist with the completeness of the ISD analysis.</p> <p>2. Combination of various indices such as IS2I, PHCI, and EPRI to ensure every aspect of the relevant process (or process node) has been effectively described.</p>	<p>Develop a means of ensuring completeness which may include:</p> <ol style="list-style-type: none"> <li>1. Guidance on how to do the ISD study and how to evaluate completeness</li> <li>2. Training and knowledge of the hazards and technology of the process and ISD options</li> <li>3. Checklists</li> <li>4. Rules for node selection</li> <li>5. Referenced examples on technology and design situations (pump circuit – here are options; choice of reactor designs, etc.)</li> <li>6. Use a checklist of the 4 principles to achieve inherently safer process at each node. Principles are as listed: Minimization, substitution, moderation, simplification (This can help set some guidelines, but</li> </ol>

					people still need to think of additional possibilities.)
2. Repeatable / Consistent	<p>Enforce ISD methodology on all processes as a means of customary safety procedure. Analysis on all possible nodes that can exist in a process would allow the application of specific ISD methodologies to each section of the process. Therefore, making it possible to apply the ISD methods in several different process with similar sections.</p> <p>Idea: Evaluate all current processes to identify an effective ISD methodology for each node to encourage consistency.</p>	<p>Nodes may have not been specifically defined for ISD analysis.</p> <p>There are no two processes that are the same.</p> <p>One plant's process may have different operating conditions and constraints as compared to another plant's process. (Tolerance on change is subjective)</p> <p>Process designers emphasize factors (cost-efficiency, environmental aspects, and inherent safety) differently according to company policies and goals.</p>	<p>(+) The Risk-Based Performance Standards (RBPS) program uses the 4 main ISD strategies and applies to it a process life cycle to ensure that it is repeatable for all.</p> <p>(+) By perceiving ISD as a process safety culture, it will be prioritized and will be consistent throughout all plants, even if processes differ.</p>	<p>1. Integrated Inherent Safety Index (IS2I) conceptual framework that utilizes flowcharts to quantify inherent safety.</p> <p>2. Process and hazard control index (PHCI) framework provides qualitative backup to purely quantitative indices such as IS2I. The PHCI is scaled subjectively according to process safety experts with a mutual agreement.</p> <p>3. Most proposed index methods, even for other attributes can be repeatedly used throughout different processes.</p>	<p>Develop a means for ISD methodology to be applied at all situations. This may include:</p> <ol style="list-style-type: none"> <li>1. Standardizing the node selection by analyzing the Process Flow Diagram for the overall process and select each inlet-outlet point as a node.</li> <li>2. Utilize indices that include cost-efficiency, environmental aspects, and inherent safety factors alongside qualitative opinions from experts.</li> <li>3. Enforcement of the usage of databases to assess past incidents. The boundary operating conditions for each plant can be controlled with the information from the database. This helps to find common ground between the company policies and goals while satisfying the boundary operating conditions. This effectively makes the interpretation of the ISD analysis consistent across</li> </ol>

					different overall processes.
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<p>3. Comparable</p>	<p>Compare ISD analysis to past safety checkups that were done just as a form of circumstance, and then improve what needs to be done, as well as show what had been done in the past can be further improved.</p> <p>Idea: Set ISD methodologies as a customary safety procedure for all process plants. This way, the safety analyses moving forward can only improve further.</p>	<p>Past methods of safety analysis may seem more attractive to clients due to novelty of ISD methodology.</p> <p>There are few defined methods to quantify inherent safety.</p> <p>Without training, a procedure on how to implement, rules of engagement etc., there is a high potential for this issue</p> <p>Or if you do not have access to other frames of reference or studies for comparison, may be naïve to what is possible or good.</p>	<p>(+) Since ISD has is a rather novel concept in process safety, there are only a few standards that have been established on this basis, which makes it easy to compare between previous process safety procedures and the new ISD methodologies.</p>	<p>1. The Equipment Process Route Index (EPRI) depends on the chemical combustibility potential of the chemicals in the process. It also depends on the specific process that is being analyzed, properties such as temperature, pressure, density, viscosity, flammability and so on. Lastly, it considers the equipment that is being used. namely, the inventory, ignition source, reactor type.</p> <p>2. A risk matrix can be used to identify the worst-case scenarios, and the likelihood of it occurring, which can be compared.</p> <p>3. All proposed index methods, even for other attributes can be used to compare inherent safety between overall processes.</p>	<p>Develop a means for effectively quantifying inherent safety in order to compare between different plants. This may include:</p> <p>1. Training and knowledge of the hazards and technology of the process and ISD options. This increases awareness throughout the chain of command and ensures ISD analysis is constantly implemented for comparison purposes.</p> <p>2. Referenced examples on technology and design situations (pump circuit – here are options; choice of reactor designs, etc.). Without this knowledge, the EPRI index would not be very helpful since nobody will understand the significance of the returned values.</p> <p>3. Additional development of theoretical accident causation models to predict possible undesired events and mitigate through enforcement of inherent safety</p>
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					<p>culture in all worker operations.</p> <p>4. Indices act more as a subjective approach to evaluation safety options and effectively help with the decision-making process. In other words, indices act more as a factor towards the bigger picture of the decision making with ISD analysis. An idea would be to accompany the index value along with a relevant recommendation. This provides understanding on what needs to be changed.</p>
<p>4. Technically sound implementation</p>	<p>Consult operators and technicians at the plant to gain their insight on technicality of ISD analysis. The implementation of ISD analysis on the process might also vary with the complexity of the overall process. For example, using a small reactor will minimize the hazard of fire and explosion. While technically sound, it is not exactly feasible on an operations perspective.</p>	<p>ISD analysis solution might be technically sound, but impractical.</p> <p>ISD analysis solution might be too complex to make any improvements</p>	<p>(+) CCPS/ AcuTech references Kletz's principle of simplification to show that the desire for technical elegance is often unrequired when a simple process can achieve the same results. The excess equipment and complexity are usually unhelpful.</p> <p>(+/-) Completed and organized technical information is required for the process in question, including information such as equipment</p>	<p>1. The Equipment Route Index (EPRI) can be utilized here to assess the specific equipment used in the process to identify if it is indeed the most suitable. However, this index can be fallible in a sense that a piece of equipment might have a more attractive EPRI index but too technical to implement.</p>	<p>Develop a means to implement ISD analysis that is technically sound. This can be achieved through:</p> <ol style="list-style-type: none"> <li>1. Compiling relevant technical knowledge to aid ISD analysis for specific nodes in a process.</li> <li>2. Conducting ISD analysis in smaller nodes for complex process might help negate issues</li> </ol>

			specifications, maintenance activities, vulnerabilities of construction materials and so forth. Without the comprehensive information, analysis cannot be done.		present due to complexity.  3. Take steps to ensure that technology that the company holds should be relatively up to date with what most ISD analyses recommendation will require.
5. Practical/Feasible application of methodologies	<p>The consideration of both micro and macro opportunities that are present in inherent safety analysis at nodes of an overall process. This enables small level changes that can be made at the different nodes to evaluate all possible hazards and improve the inherent safety of the overall process by challenging the hazards that are present at each node.</p> <p>Idea: Implement ISD strategies to simplify overall process or specific nodes.</p>	<p>Process life cycle may have a process that must operate at hazardous conditions.</p> <p>The reactant used or the product made might be inherently hazardous.</p> <p>There is simply not enough space for distancing to take place.</p> <p>Company does not have enough resources to implement large scale changes to overall process.</p>	(+) The consideration of micro and macro opportunities. Namely, the specific hazards at individual nodes to evaluate all known hazards.	<p>1. The EPRI index method would be useful here because it involves the equipment in question as well. E.g. If there was an overall process with 15 nodes in which all nodes were a different reactor type or piece of equipment, the EPRI would be able to evaluate and quantify the inherent safety level at each node.</p> <p>2. A risk matrix can be used to identify if the worst-case scenario would be feasible.</p>	<p>Develop an ISD analysis that would be practical to conduct for all processes. This can be achieved through:</p> <p>1. The identification of all possible hazards are the node level instead of an overall process level. This increases the practicality of the analysis because improvements are more likely to be made when a small, specific hazard is identified at each node. Changing a whole overall process to achieve improved inherent safety would not be very feasible.</p> <p>2. The usage of stated indices (EPRI) can assist in showing what equipment would be inherently safer for each node.</p>

					<p>Therefore, increasing the practicality of using that specific equipment.</p> <p>However, index values are not entirely meaningful without practical analysis and can't give detailed results like what specific issues that are present and what it means. Therefore, the accompaniment of relevant recommendations would provide understanding on what needs to be changed.</p>
6. Efficient implementation of the analyses	<p>Ensures that ISD analysis can be done in a significantly timelier manner as compared to standard safety analysis procedure.</p> <p>Idea: Implement an ISD state of mind for workers and managers so more opportunities for change can be explored without a full-scale HAZOP having to take place.</p>	<p>Methodology might not be adopted by practitioners because they are used to doing HAZOP and such while ISD methodology is novel.</p> <p>Thoroughness of traditional safety analysis methods tend to decrease efficiency in a sense that it takes forever to give unhelpful info.</p>	<p>(+) CCPS/ AcuTech methods cover how the education and awareness of ISD is act as a philosophy within all employees. This is so an ISD analysis can be done more efficiently in a sense that the day-to-day operators and engineers will most likely be able to identify the opportunities for change based on ISD principles much quicker rather than going through a checklist that might not be relevant.</p>	<p>1. A risk matrix can be used by the operators of each specific node of the overall process to identify which hazards would be prioritized as well as which hazards can be mitigated almost immediately through the implementation of ISD principles.</p>	<p>Develop an ISD analysis method that would be efficient and take significantly less time than common safety analysis procedure. This can potentially be achieved by 1. Inform workers and practitioners that HAZOP focuses on layers of protection and ISD methodology is more efficient in identifying the hazards through the 4 principles. HAZOP has many distractions that lead people away from seeing the hazards. This level of awareness will</p>

					<p>speed up ISD analyses.</p> <p>2. Referenced examples on technology and design situations (pump circuit – here are options; choice of reactor designs, etc.). This base of knowledge of the available technology will help in the hazard identification process, instead of continuously looking at a predetermined checklist of things that might not even apply.</p>
<p>7. Analysis produces cost effective results including possible options</p>	<p>Identifies that by replacing parts of an overall process with “inherently safer” alternatives, that overall cost would be decreased as a result. A format cost effectiveness analysis needs to be implemented. For example, if a process plant were to be inherently safer, the rate of accidents would greatly decrease, thus, effectively decreasing the company’s obligation to compensate for legal fees and public, healthcare costs.</p> <p>Idea: Begin the application of ISD analysis onto new processes to show that in the long run, more is saved when incident rates are minimized.</p>	<p>There is no definitive method to quantify inherent safety, although it can be attempted</p> <p>Without a full plant specification, it is impossible to even attempt a cost analysis based on inherent safety.</p> <p>Cannot display how much is saved if there are no accidents that happen at all. (One can also argue that they could have made</p>	<p>(+) The Broad View and Life Cycle Cost of Alternatives (16.5.1) concept can be applied to provide a broader view of a process so that an inherently safer design would be appreciated and seen as a more cost effective alternative.</p> <p>(+/-) The life cycle cost (LCC) compares initial investment options and identifies the minimum cost option. If ISD options were to be applied here, one can potentially quantify inherent safety. However, training to assist in the estimation</p>	<p>1. The Conventional safety cost index (CSCI) involves taking the ratio of the sum of process control measures and add-on safety measures to the cost of losses: the sum of production loss, asset loss, human health loss, and environmental cleanup cost. The ratio of these to sums provides an effective index to produce cost effective options.</p>	<p>Develop a universal method to exhibit all possible options that would result in the maximization of cost effectiveness. This can be achieved through:</p> <p>1. The usage of CSCI index method, which makes it possible to measure the inherent safety index at each node, and a cost analysis can be done at that specific node.</p> <p>2. The implementation of the four ISD</p>

		<p>the process not as inherently safe and still have no accidents.)</p> <p>Requires a long time to prove. (Danger can be identified in a blink of an eye whereas a type of safety period would have to be defined to show if a process is officially “safe”.</p> <p>Every plant has a minimum productivity, which may constrain the potential options from analysis.</p>	<p>of LCC would be required.</p> <p>(+/-) Method does not include a formal quant cost effectiveness analysis but could be used if necessary. Usually the team’s assignment is to identify opportunities and then subsequently there must be further consideration including feasibility, alternatives, costs, benefits, time to implement, effectiveness in risk reduction. (Importance must be considered by these factors and then a decision made on how to proceed).</p>		<p>strategies. (E.g. Can the temperature be decreased? Can the chemical be substituted? Is it necessary to operate at these conditions?)</p> <p>3. The combination of an index method and a relevant qualitative recommendation would be able to move towards a relatively inexpensive way to minimize risk at a low cost. This will be done through the clear understanding of what needs to be changed for a specific node in a process. Discussions will need to take place in order to find out how much the implementation of the recommendation would cost, to weigh the cost-effectiveness against the inherent safety.</p>
8. Rigor	<p>By strictly maintaining clear boundaries and constraints on what can or cannot be done, an inherently safer “state of mind” would be instilled upon technicians and operators. When these people are constantly thinking of the ISD concepts, the overall process</p>	<p>“Normalization of Deviation” belief may cause operators in process plants to normalize the risks and not take inherently safer precautions. Therefore,</p>	<p>(+) Rigor on checklists, training, ISD analysis, and decision making would increase the overall reliability of ISD.</p> <p>(+) CCPS/ AcuTech methods include general applications of</p>	<p>1. The Inherent Safety Index (ISI) proposed by Heikkilä involves the sum of the chemical inherent safety index, which contains chemical factors that affect the inherent safety of processes, these</p>	<p>Develop a method to ensure rigor in the work environment and in ISD analyses by including:</p> <p>1. Training and knowledge of the hazards and technology of the</p>

	<p>becomes inherently safer due to their actions.</p> <p>Idea: Establish a rule for ISD actions in the workplace and conduct a test that assesses the “state of mind” of the workers to ensure they are on the right track. The test can be done on either a monthly or bimonthly basis. This provides constant awareness to both leaders and staff to increase overall sensitivity in operations.</p>	<p>crossing the boundaries of what can or cannot be done, ultimately posing potential hazards in their actions. (E.g. Crossing the street when the walk sign is not on, but there is no traffic. This is an example of how people normalize the risk of being hit by a car by going against the constraint/ rules.)</p> <p>Lack of rigor can lead to insufficient or incomplete ISD analysis.</p>	<p>ISD onto the life cycle stages (a form of rigorous ISD analysis) that are involved within a specific process, which enables a more in depth understanding of what can be changed to benefit the inherent safety of the overall process.</p>	<p>factors act as sub-indices to calculate the index, and the process inherent safety index, which expresses the safety of the process through the sub-indices like inventory, temperature, pressure, equipment safety, and process structure.</p>	<p>process and ISD options. This increases awareness throughout the chain of command and ensures ISD analysis is constantly implemented. This ensures that ISD becomes a safety culture rather than an extra, optional step.</p> <p>2. Enforcement of company rules and policy to go through certain guidelines and set a high bar for what is considered a “good enough”, complete ISD analysis. This can be reinforced using occasional assessments.</p> <p>3. Additional development of theoretical accident causation models to predict possible undesired events and mitigate through enforcement of inherent safety culture in all worker operations.</p> <p>4. Rigorous use and enforcement of a checklist of the 14 principles to achieve inherently safer process at each node. Principles are as listed: Minimization, substitution,</p>
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<p>9. Scalable</p>	<p>The ISD methodologies used for small scale processes should also be able to apply to large scale processes. This can be ensured through the usage of dimensionless quantities.</p>	<p>Large processes are more likely to be more complex than small processes.</p> <p>Variation in complexity may impact effectiveness of index methods for processes of different scales</p>	<p>(+) CCPS/AcuTech use a risk matrix to measure risk reduction potential. Indices use yardstick scale for measuring output and differences.</p> <p>Advantage of measurable is it gives perspective. Best form of measurable would be absolute risk measurement but relative risk measurement is also possible and useful.</p>	<p>1. Most index methods proposed in the other attribute sections can be used, but effectiveness might vary with complexity of overall process.</p>	<p>Develop a method that can be applied to processes of different complexity through:</p> <ol style="list-style-type: none"> <li>1. Proper identification of appropriate nodes of the overall process to potentially negate the relevance of complexity of the process.</li> <li>2. Usage of a more subjective index method such as PHCI that is based on mutual agreements of experts of the field.</li> </ol>

