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REVIEW OF SOCIAL METRICS AND TOOLS: DEVELOPMENT OF COMPREHENSIVE QUANTIFICATION OF SOCIAL SUSTAINABILITY IN PROCESS DESIGN

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ABSTRACT: The concept of sustainable design has emerged as a new paradigm. Sustainability combines economic, environmental and social aspects of Process design. In our research all the available metrics, tools that are being used for social quantification with good definition, description and calculation methodology is reviewed. Social prospects and shortcomings of each available tool is assessed. Then a new tool is proposed which considers both the inherent safety and occupational health quantification for sustainable process design. The method is tailored for the process research and development stage by including only such chemical properties and process operating conditions which are obtainable at early design stage. With the help of the developed standard index scale and the retrofitted SUSTAINABILITY EVALUATOR the best socially sustainable process design can be assessed.

KEY WORDS: process social sustainability, inherent safety, occupational health, retrofitted SUSTAINABILITY EVALUATOR

1. Introduction

With the advent of the 21st century, green chemistry is being incorporated in the design of chemical processes, eventually shifting the industrial focus from economic concerns to sustainability concerns. As economics of the industrial processes was initially dictated as the main constraint in the design of chemical process plants, health and safety of the workers and public welfare (social concerns) have only recently become another main constraint (Samli, 2011).Although researchers have put forth much effort s to quantify sustainability, an important drawback is that social quantification at the early design stage has not generally been considered from both a health and safety perspective successfully. As the term 'sense making of social sustainaibility' itself is abstract, a well defined methodology is needed to quantitatively measure the social dimension of sustainability.

Social sustainability metrics, indicators and tools developed by different researchers have been reviewed in this paper. Social aspects, applicability potential as well as shortcomings of the available tools in case of social quantification at early design stage have been analyzed. The ability to measure social sustainability using indicators or metrics is important because it will assist in comparing processes as well as assessing positive change towards health and safety sustainability over a period of time. It could be used to evaluate alternatives such as technical alternatives e.g. different raw materials and process improvement options and/or business alternatives, for example, different supplier and acquisition options (Shadiya, 2010a). Furthermore, it can identify the means of combining the health and safety consideration along with economic impacts and environmental effects.

One thing to be mentioned is that sense making of social sustainability by quantification is a complex issue. This is because it is difficult to transform social issues into scientific vision (Shadiya, 2010a). One of the focus of this research is to develop new metrics and a tool for weighing of comprehensive process social sustainability with a modified version of the developed Excel based tool titled the "SUSTAINABILITY EVALUATOR" (Shadiya, 2010b)

2. Health and Safety Screening Tools

Modern process industries passed the age of add-on protective systems already and several health and safety risk assessment methods have been developed. This section describes available screening tools for evaluating various aspects of process health and safety as follows:

2.1 Dow Fire and Explosion Index

The Dow Fire and Explosion Index was developed to quantify the potential damage from fire and explosion hazards in chemical processing plants that handle 1000 pounds or more of flammable, combustive and reactive toxic chemicals (Kavitha, 2003). The Dow Fire and Explosion index involves a step by step analysis as depicted in the flow chart shown in Figure 2.2 (Shadiya, 2010a).

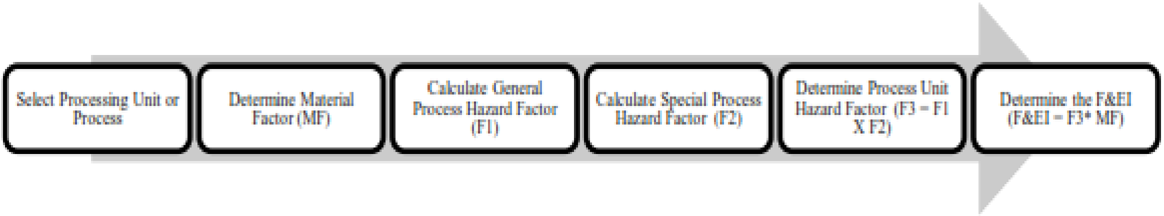


Figure1: *Dow Fire and Explosion Index Calculation Steps*

The Dow Fire and Explosion Index have been used by many researchers to incorporate safety into chemical process design. It has been implemented into an optimization framework where technical, economic and safety considerations are being met for process design at the conceptual stage (Suardin et al., 2007). A modified version of this index which involves including credit for loss control measures has been demonstrated on an ammonia synthesis reactor (Gupta et al., 2003). The index has also been used as tool to classify hazards for the manufacture of epichlorohydrin (Khan and Abbasi, 1997). To assess the risk of fire and explosion for operations taking place in the Microbiology Laboratory at the University of Reno Nevada, the Dow Fire and Explosion Index was implemented (Kavitha, 2003).

The limitations of the Dow Fire and Explosion are that it only addresses fire and explosion safety concerns but it does not address toxicological data (Shadiya, 2010a).

2.2 Mond Index:

The Mond Inded(ICI,1985) has been developed from the 1973 version of the Dow F&E

Index. The Pricipal modifications to the Dow method include (Lees, 1996): 1) wider range of processes and storage installations can be studied, 2) covers processing of chemicals having explosive properties, 3) improved hazard consideration for hydrogen, 4) additional special process hazards, 5) toxicity included into the assessment. It differs from the Dow fire and explosion index in that it can evaluate safety impact of wider ranges of chemicals such as explosive properties and toxicity assessments. The Mond Index also incorporates hazards credits for processes with safety control devices (Khan and Abbasi, 1998).

2.3 NFPA 704

NFPA 704: Standard System for the Identification of the Hazards of Materials for Emergency Response is a standard maintained by National Fire Protection Association of United States. First tentatively adopted as a guide in 1960 (NFPA No. 704M, 1969) and revised several times since then, it defines the "fire diamond" used by emergency personnel to quickly and easily identify the risks posed by materials. The four divisions are typically color-coded with red indicating hazardous flammability, blue indicating level of health hazard, yellow for chemical reactivity, and white containing codes for special hazards. Each of health, flammability and reactivity is rated on a scale from 0 (no hazard) to 4 (severe risk). This helps determine what, if any, special equipment should be used, procedures followed, or precautions taken during the initial stages of an emergency response.

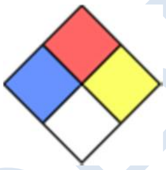


Figure2: *NFPA 704 Fire Diamond.*

Although NFPA704 has been proved to be very effective for fire safety it has some limitations in measuring the overall social sustainability. One example is the current debate regarding flame retardants. Although there is limited data available from human studies, some flame retardants are considered possible carcinogens, while other health effects may include damage to endocrine, immune, reproductive, and nervous systems. The ability of some flame retardants to bio-accumulate raises concern about the potential for harm to firefighters and the general public from even low levels of exposure (Vecchiarelli,2014).

2.4 Hazard and Operability Analysis (Hazop)

A HAZOP analysis is a procedure that is completed for existing and new facilities and it involves identifying all the hazards and operability issues in a chemical process. In the HAZOP study, the safety impact of all the different equipment found in a process, specifically looking at the potential hazards when the process deviates from design conditions is evaluated (Dunjó et al., 2010). Kletz (1991) has pointed out an important difference between a conventional Hazop of a line diagram and a Hazop of a flowsheet (i.e. the process concept). In a conventional Hazop deviations from design conditions are assumed to be undesirable and ways of preventing them are looked for. Also in the Hazop of a flowsheet deviations are generated but they are actually looked for to find new process alternatives. Although HAZOP analysis has been extensively used in the chemical process industry, it has some limitations. It is time consuming, as only one accident scenario can be looked at a time. It cannot be used during conceptual stages of design, as detailed process and instrumentation diagrams must be completed, requiring Knowledge and expertise in order to complete the assessment accurately (Shadiya, 2010a).

2.5 Simulation of Chemical Industrial Accidents Software Package (SCIASP)

THE Simulation of Chemical Industrial Accidents Software Package (SCIASP) was developed to evaluate the possible risk of accidents in chemical processes (El Harbawi et al., 2008). This graphical based tool is able to perform hazard analysis that determines risks and damage associated with accidental releases, fires and explosions. This newly developed software is a useful tool for risk assessment because it can be used as a decision making tool to compare the safety risks of different processes (Shadiya,2010a).

2.6 Mortality Index

THE Mortality Index was suggested by Marshall (1977) evaluates the fatality of lethal chemical substances. The mortality index is shown in the equation below (Shadiya, 2010a).

Mortality Index =Number of Deaths / Mass of Toxic Substance

2.7 The Instantaneous Fractional Annual Loss (IFAL) Index

THE Instantaneous Fractional Annual Loss (IFAL) Index, developed to identify hazards from pool fires, vapor fires, uncondensed cloud explosions, condensed cloud explosions and internal explosions is a complicated system that needs to be calculated with a computer (Singh and Munday, 1979; Munday et al., 1980). This index was proposed by the United Kingdom Insurance Technical Bureau, to access hazards for each piece of process equipment in order to estimate insurance rates (Cox, 1982).

2.8 Hazard Identification and Ranking (HIRA)

THE Hazard Identification Racking (HIRA) methodology was developed by Khan and Abbasi (1998) to evaluate the risk of fire, explosion and toxic release. This methodology consists of two indices: the fire and explosion damage index and the toxicity damage index. This methodology has been demonstrated on the sulfolane production process and the safety risk was determined. To validate this methodology, results of other indices such as the Dow Fire and Explosion Index, IFAL Index and the Mond Fire and Explosion Index have been compared to the HIRA methodology. The results of the comparison show that HIRA is more sensitive and accurate compared to other methods (Khan and Abbasi, 1998). One drawback of HIRA is that it does not tell if existing control systems are sufficient or need modifications. It also does not incorporate an emergency response plan such as toxic release control and firefighting equipment into the calculation (Khan et al.,2001). A new tool to improve some of the limitation of HIRA was proposed and this was called the Safety Weighted Hazard Index (sWeHI). The Safety Weighted Hazard Index was developed by Khan et al. (2001) to accurately and precisely address safety concerns in chemical industry while integrating credits for safety measures that are already in place (Shadiya,2010a).

2.9 Maximum Credible Rapid Risk Assessment (MAXCRED)

THE Maximum Credible Rapid Risk Assessment (MAXCRED) is a computer software developed by Khan and Abbasi (1999) to simulate accident and damage potential in order to evaluate safety risk of processes in the chemical industry. It has been demonstrated on an industrial sulfolene production process (Shadiya, 2010a). Two different accident scenarios namely boiling liquid / vapor cloud explosion followed by flash fire and confined vapor cloud explosion have been modeled for the British Petroleum Texas City Refinery incident. This was developed to show that hazard assessment can prevent safety incidents and provide adequate emergency response (Khan and Amyotte, 2007). MAXCRED was also used for damage prediction for an oxidation based ethylene oxide plant (Khan et al., 2003).

PROTOTYPE Index of Inherent Systm (PIIS)

EDWARDS and Lawrence (1993) have developed a Prototype Index of Inherent Safety (PIIS) for process design. The inherent safety index is intended for analyzing the choice of process route; i.e. the raw materials used and the sequence of the reaction steps. The PIIS has been calculated as a total score, which is the sum of a chemical score and a process score. The chemical score consists of inventory, flammability, explosiveness and toxicity. The process score includes temperature, pressure and yield. It has some clear advantages over some other numerical indices in early design stages (Heikkila et al.,1999).

IT has been argued that an overall inherent safety index, such as the PIIS, incorporates some kind of build-in judgment of the relative importance of the various types of hazards. The user has to defer to the judgment of the developer of the index or has to modify it to incorporate his own judgment. In the latter case the results are not any more comparable with other users (Hendershot, 1997).

2.10 Inherent Safety Index

THE Inherent Safety Index was proposed by Heikkila (1999) to evaluate process safety. There are two categories of safety indexes presented by this researcher and they are chemical and process safety index. The summation of these two indices yields the Inherent Safety Index. The chemical index describes how raw materials, products, by- products, and intermediates interactions affect safety of a process. While the process safety index depicts how equipment configuration and operating conditions can impact the safety of a process (Shadiya, 2010a).

IN spite of its limitation to model safety risks resulting from deviations in operation conditions, other researchers used the inherent safety index. It was integrated into an expert system called iSafe for ranking safety of process flow sheet structure (Palaniappan et al., 2002). It was used to select the safest production route from 10 different options for acetic acid (Palaniappan et al., 2004). This index was used to access the safety of simulated chemical and mechanical heat pump systems and the safest option was selected based on the inherent safety index (Ajah et al., 2008). This inherent safety methodology has been incorporated into the modified SUSTAINABILITY EVALUATOR for this research and will be discussed in details in section 4.3.1.

2.11 The Dow Chemical Exposure Index

THE Dow Chemical Exposure Index (1998), CEI gives a very comprehensive method of assessing health hazards caused by acute exposure to chemicals. The assessment is carried out for each source identified to have a potential for releasing chemicals (Hassim and Hurme, 2010).

ONE drawback of CEI is that it evaluates acute health hazard risk to people based on chemical release incidents and failed to measure the long term effects on workers which is essential from occupational health point of view.

2.12 Toxicity Hazard Index

TOXICITY Hazard Index was introduced by Tyler, Doran, and Greig (1996). It ranks the relative acute toxic hazards of different chemical production units. This Mond-like index evaluates the toxicity potential of a unit, considering only short term events and acute effects based on inhalation route of exposure. It has been constructed so that the overall pattern closely follows the framework of the Mond index (Hassim and Hurme,2010).

LIKE HIRA method (Khan and Abbasi, 1998), THI is also a safety-type assessment method which deals with acute toxicity alone and only treats the short-term accidental events, but not the low level and continuous releases.

2.13 UK Scheme

THIS was the model developed by a working group established by the Health and Safety Commission's Advisory Committee on toxic substances (Maidment, 1998; Russel, Maidmetnt, Brooke, and Topping, 1998). The scheme scrutinizes both the intrinsic health hazard of substances used at work and surrogates for exposure potential particularly to employees with the ultimate target of appropriate control strategies identification.

THE shortcomings of the scheme is in its applicability for design stage implementation as it is targeted particularly for existing small and medium size plants.

2.14 *INSET Toolkit*

THIS toolkit was an outcome of INSIDE Project (2001) capable of assessing SHE aspects as well as other feasibility factors. The four stages implementation of the toolkit is shown below:

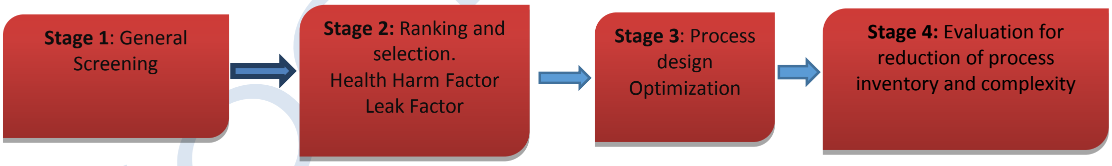


Figure 3: *Four stages of INSET Toolkit*

ONLY stage 2 deals directly with the ranking and selection of SHE aspects (Hassim and Hurme, 2010). The health performance of the routes is evaluated based on the hazardous materials properties relating to health effects, the likely fugitive emission rate of that material as well as the chance that people are exposed to this. For chemical properties the Health Harm Factor (HHF) is determined from R-phrase and qualitative classification. The Leak Factor (LF) is provided to estimate the fugitive release rate from process equipment and manual activities. The potential exposure is assessed only by estimating the number of locations where manual-handling operation will be carried out. The overall health index is calculated from these scores (Hassim and Hurme, 2010).

MALMEN (1997) and Ellis (1997) who applied the toolkit identified some difficulties such as long time required in index calculation, the need to screen a large number of alternatives, and the requirement for analyzing complex issues at early stages.

2.15 Occupatinal Health Hazard Index

OHHI was developed by Johnson (2001) in her Master's thesis for assessing the health hazards in design concepts. The disadvantage of the OHHI method is that some factors for example very concise and questionable evaluation of fugitive emissions and over evaluation of some factors requiring excessive data for example material properties and operational maintenance activities. 2.16 Process Route Healthiness Index

HASSIM and Edwards (2006) proposed the PRHI methodology which is complicated and lengthy. Some disadvantages of this index system as described by Hassim and Hurme (2010) are: firstly, PRHI requires plenty of information some of which not available at early design stage. It is also inflexible as a result of 'throughout the process' data requirements. Besides, the index has the disadvantage of indirectly assessing several factors such as propensity for chemical emissions repeatedly.

2.16 Inherent Occupational Health Index

THE Inherent Occupational Health Index (IOHI) was developed by Hassim and Hurme (2010) for assessing the health risks of process routes during process research and development stage by including only such properties of chemical and operating, which are available already in this early stage. An inherent conditions of process occupational health hazard has been defined here as a condition, inherent to the operation or use of material in a particular occuapation, industry or work environment, that can cause death, injury, acute or chronic illness, disability, or reduced job performance of personnel by an acute or chronic exposure (Hassim and Edwards, 2006). As described by Hassim and Hurme (2010), inherent occupational health strives to eliminate or reduce occupational health hazards by trying to eliminate the use of hazardous chemicals, process conditions, and operating procedures that may cause occupational hazards to the employees. The objective has two facades: Firstly to minimize the risk of inherent properties of chemicals (toxicity and high vapor pressure for example) by using friendlier chemicals or the chemicals in safer physical condition (such as lower temperature) to eliminate the exposure. Secondly to reduce such process steps or procedures which involve inherent danger of exposure of the chemical. Examples of such operations are some manual operations where the worker is in close contact with the material such as manual handling and dosing of chemical, emptying, and cleaning of the equipment etc. (Hassim and Hurme, 2010).

Table 1: *Summary of the Metric, Tools, Indicator and Index Systems*

Initiative	Organization/ Year	Brief Description	Inclusion of social sustainability issues	Analysis
The Dow Chemical Exposure Index	AIChE,1998	The index uses a methodology for estimating airborne quantity released	Guide to rating the relative acute health hazard potential of a chemical release to workers and the neighboring community	It evaluates the acute health hazard risk to people from chemical release incidents, and not the long-term effects on workers during normal operation.
CSD Indicators for sustainable Development	UN, 1995	50 core indicators part of a set of 96 indicators. The framework contains 15 themes, which are no longer explicitly categorized into four pillars of sustainable development	Social indicators include (1) Poverty, (2) Governance, (3) Health, (4) Education and (5) Demographics	Not applicable for process sustainability.
Well-being assessment	IUCN –The World Conservation Union and the International Development Research Centre (IDRC), mid 1990s	It is based in the Well-being of Nations survey, introducing the "Egg of Well-being" formed by the Ecosystem Well-being Index (EWI) and Human Well-being Index (HWI)	HWI focuses on (i) health and population (ii) wealth; (iii) knowledge and culture; (iv) Community; (v) Equity. Aggregation uses several techniques (unweighted averages, weighted, and lowest value)	Concept of 'Barometer of sustainability' and sustainability assessment flowchart is significant. May help to choose indicators and performance criteria.
Toxicity Hazard Index	Tyler, Thomas, Doran, and Greig (1996)	Ranks the relative acute toxic hazards of different chemical production units.	Evaluates the toxicity potential of a unit, considering only short-term events and acute effects based on inhalation route of exposure developed.	It deals with acute toxicity alone rather than the overall aspect of health hazards.
UK Scheme	(Maidment, 1998; Brooke, 1998; Russell,	Accounts for effects of chemicals exposure particularly to	The developed model scrutinizes both the intrinsic health hazard of substances used at work as well as	Targeting on existing plants thus making it inconvenient for design stage implementation.

	Maidment, Brooke, & Topping, (1998)	employees, with the ultimate goal of identifying appropriate control strategies	surrogates for exposure potential.	
The INSET Toolkit	INSIDE Project, (2001)	The toolkit incorporates four stages of implementation. Stage 1 involves general screening, Stage 2 deals directly with the ranking and selection of process routes based on the SHE aspects, Stage 3 concerns with process design optimization of the route(s), Finally, the initial process design is developed in Stage 4	For chemical properties, the Health Harm Factor (HHF) is determined from R- phrase and qualitative classification. The Leak Factor (LF) is provided to estimate the fugitive release rate from process equipment and manual activities	The health performance of the routes is evaluated based on the hazardous material properties relating to health effects, the likely fugitive emission rate of that material as well as the chance that people are exposed to this. Aside from being complex, this method requires massive detailed information.
City Development Index	Habitat, 2001	Formed by five indices: Infrastructure, Waste, Health, Education and City Product	Three indices measure aspects of social sustainability, but relevant issues are left out. The overall aggregation considers all the indices to have the same weighting.	Not applicable for process social quantification.
Process Route Healthiness Index (PRHI)	Hassim & Edwards (2006)	The index includes wide range of factors in a single evaluation stage, requires plenty of information	PRHI, the work still serves as the first methodology, formally published in this area	Not suitable for a simple and quick application. It is also inflexible as a result of the data requirements for the application. Index has the disadvantage of indirectly assessing several factors.
Occupational Health Hazard Index (OHHI)	Johnson (2001)	Different factors considered for assessments	Earlier version of the method PRHI	Some factors are evaluated very concisely so that the accuracy is questionable. Some factors are over-

				evaluated requiring excessive data
Mortality Index	Marshall (1977)	Mortality Index =Number of Deaths / Mass of Toxic Substance	Evaluates the fatality of lethal chemical substances	Not directly applicable at process design stage.
Safety and Health Evaluation Tools	Shadiya ,2010	Economic, environmental and social all three are quantified and sustainability measured through the 'SUSTAINABILITY EVALUATOR'	Two categories of metrics are discussed: 1.Process Safety Risks and 2.Health Risks	Disease risk assessment is incorporated in our research. A modified version of the SUSTAINABILITY EVALUATOR is also incorporated.
Inherent Process Safety Index	Heikkila, 1999	Chemical inherent safety index and process inherent safety index.	Only addresses safety concerns. Applicable for assessing the safety of a chemical process at all stages of design	Inherent safety index with modifications is incorporated in our research.
Sustainability Indicators	Afgan et al., 2000	Sustainability indicators	Indicator system has limited applications as it has been tailored towards accessing the impact of energy systems.	The assessment formula proposed may be adopted for social quantification. But not much applicable for process social sustainability.
Dow Jones Sustainability Index	Knoepfel, 2001	Sustainability index	Most of the indices are qualitative measures and are not applicable to early stages of design.	Not applicable for process social quantification.

BASF Socio- Eco-efficiency Metrics	Saling et al., 2002; Saling et al., 2005	SEE Balance	Useful in evaluate the impact of products and process during detailed design.	The social metrics presented, pose difficulty in terms of correlation with process design parameters.
IChemE Sustainability Metrics	Tallis, 2002	Sustainability metrics	For the social metrics presented, it is difficult to correlate them with process design parameters. Useful in assessing the sustainability of production processes	Potency Factor Concept for health quantification may be applicable.
Indicators of sustainable production	Krajnc and Glavič, 2003	Social indicators	Too many metrics were suggested and not all of them are applicable to early stages of design. Useful in assessing the sustainability of an operating unit	10 social indicators with quantification is proposed. Strategy may be develop to incorporate them in future research.
Global Environmental Risk Assessment (GERA) Index	Achour et al., 2005	GERA index	Useful in addressing health and safety risks of an operating unit and stream	Not Applicable for process social quantification
BRIDGES to Sustainability Metrics	Tanzil and Beloff, 2006	Sustainability Metrics	Metric categorizes environmental impact of pollution into one metric versus breaking it down into individual concerns such as global warming, acidification	Not Applicable for process social quantification

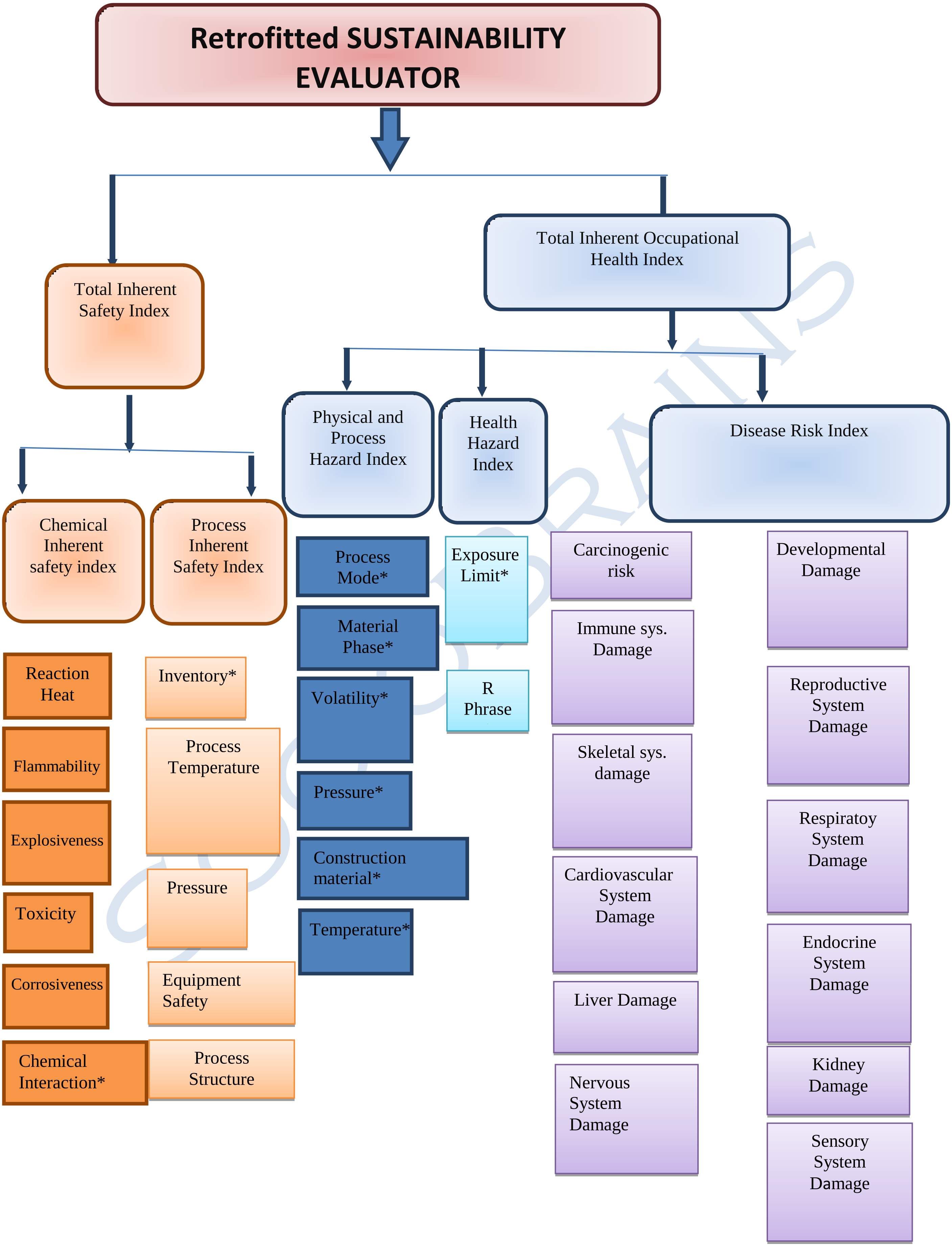
Three Dimensional Sustainability Metrics	Martins et al., 2007	Sustainability metrics	Two metrics have been presented for environmental impact and health and safety risk, the direct correlation between operating conditions, chemical process risk and environmental impact was not addressed.	Useful in evaluating the sustainability of an industrial process. Determination of Hazard Class proposed in this paper may be used to calculate the safety factors for different chemicals used in the process.
Sustainability Indices	Tugnoli et al., 2008b	Sustainability indices.	Useful in evaluating the sustainability of chemical process alternatives.	Quantitative assessment of the inherent safety during early process design was developed. Not all metrics are applicable to early stages of design.
AIChE Sustainability Index	"AIChE Sustainability Index: Strategic Commitment to Sustainability ," 2008	Sustainability index	Most of the indices are qualitative measures and are not applicable to early stages of design.	Applicable for comparing different companies 'performance .Not Applicable for process social quantification
Systematic Modular	Othman et al., 2010	1.safety during Operation	Effect of chemical emissions on human	Useful in assessing the impact of a process
Framework		2.operability of the plant 3.safe start-up and shutdown 4. design should meet location specific demands.	health was not presented.	during early stages of design.

Dow Fire and Explosion Hazard Index	Dow, 1987	The Unit Hazard Factor and the Material Factor	1) Quantify the expected damage of potential fire and explosion incidents in realistic terms, 2) identify equipment that would be likely to contribute to the creation or escalation of an incident and 3) communicate the fire and explosion risk potential to management.	They are best suited to later design stages when process equipment, chemical substances and process conditions are known.
The Mond Index		The Unit Hazard Factor and the Material and Layout Factor	1) Wider range of processes and storage installations can be studied, 2) covers processing of chemicals having explosive properties, 3) improved hazard	Modifications to improve the applicability of Dow method
Hazard and Operability Analysis (Hazop)	Kletz, 1992	Guide words: No, not; more, less; as well as; part of; reverse; other than; sooner, later; other place	Identification of process disturbances with the guide words	Qualitative technique.
Prototype Index of Inherent Safety (PIIS)	Edwards and Lawrence (1993)	Chemical score Process score	Chemical score: inventory, flammability, explosiveness and toxicity Process score: temperature, pressure and yield	This method is very reaction oriented, has some clear advantages over some other numerical indices in early design stages

			Total score: sum of the chemical and process scores	
Hazard Identification and Ranking (HIRA)	Khan and Abbasi (1998).	The fire and explosion damage index and the toxicity damage index Safety Weighted Hazard Index (sWeHI)	A five step procedure has been suggested.	sWeHI accurately and precisely address safety concerns in chemical industry while integrating credits for safety measures that are already in place.
Maximum Credible Rapid Risk Assessment (MAXCRED)	Khan and Abbasi (1999)	Computer software	A number of different risk assessment models for fire, explosion, toxic release and dispersion have been incorporated.	This was developed to show that hazard assessment can prevent safety incidents and provide adequate emergency response
Inherent occupational health assessment during process research and development stage.	M. H. Hassim and M. Hurme. 2010	Index for Physical and Process Hazards(I PPH) and Index for Health Hazards (I HH)	1. Hazard from the chemicals present and the potential for the exposure of Worker to the chemicals 2. Additive type, average-type, and worst case-type index calculations.	A quantitative standard scale for the index is developed to allow health level assessment of a single process. Inherent Occupational Health Index with modification is incorporated in our quantification approach.

3. RETROFITTED SUSTAINABILITY EVALUATOR TOOL:

BASED on the review of all the available metrics, indicators and tools a new social quantification tool is proposed as follows which incorporates broadly two major aspects of social sustainability: 1. Inherent Safety and 2. Inherent Occupational Health. The tool is applicable through a retrofitted version of the SUSTAINABILITY EVALUATOR. The SUSTAINABILITY EVALUATOR introduces a methodology which encompasses economic, environmental and social –all three dimensions by evaluating the sustainability of a process and or compare process alternatives to select the most sustainable process.


Retrofitted SUSTAINABILITY EVALUATOR
Total Inherent Safety Index
Total Inherent Occupational Health Index
Chemical Inherent safety index
Process Inherent Safety Index
Physical and Process Hazard Index
Health Hazard Index
Disease Risk Index
Reaction Heat
Flammability
Explosiveness
Toxicity
Corrosiveness
Chemical Interaction*
Inventory*
Process Temperature
Pressure
Equipment Safety
Process Structure
Process Mode*
Material Phase*
Volatility*
Pressure*
Construction material*
Temperature*
Exposure Limit*
R Phrase
Carcinogenic risk
Immune sys. Damage
Skeletal sys. damage
Cardiovascular System Damage
Liver Damage
Nervous System Damage
Developmental Damage
Reproductive System Damage
Respiratoy System Damage
Endocrine System Damage
Kidney Damage
Sensory System Damage

3.1 Innovation and originality of the proposed tool:

1. THIS tool successfully combined quantification of both the inherent safety and occupational health at the same time for a single process comprehensively using the retrofitted SUSTAINABILITY EVALUATOR.

2. IN this research the SUSTAINABILITY EVALUATOR has been retrofitted for evaluating the social sustainability comprehensively. The metrics and indices incorporated from various researchers have been elaborated and/or changed so as to develop a new social quantification tool apart from the original SUSTAINABILITY EVALUATOR. Some of such modifications are:

- Social Indices are divided into two parts: 1. Total Inherent Safety Index and 2. Total Inherent Occupational Health Index. The concept of Occupational health is incorporated by the author of this paper.
- Total Inherent Safety Index has been divided into two parts. 1. Chemical Inherent Safety Index and 2. Process Inherent Safety Index. This bifurcation will help to understand the quantitative impact of safety with greater accuracy and acceptance.
- New safety indices have been incorporated. 1. Chemical Interaction and 2. Inventory
- Equipment safety has been separately measured in inside battery limit area (ISBL) and outside battery limit area (OSBL)
- Total Inherent Occupational Health Index has been divided into three parts. 1. Chemical and Process Hazard Index, 2. Health Hazard Index and 3. Disease Risk Index. Physical and Process Hazard Index and Health Hazard Index have been calculated based on the process reactions which is also a contribution of this research.
- Total eight different Occupational health indices have been incorporated. Six of those are from Physical and Process Hazard Index: 1. Mode of Process 2.Material phase 3.Volatility 4.Pressure 5.Corrosiveness 6.Temperature. Two of those are from Health Hazard Index: 1.Exposure Limit and 2.R-Phrase.
- For the Material Phase metric, a new criterion has been developed titled as 'continuous with recycle stream'.
- Evaluation of toxic exposure impact of the acrylonitrile process. The impact value was measured for both the base case and the optimized case.
- The index scale has been calibrated in this research which differs from the scale followed by different researchers so as to make a harmonious comparison between the base case and optimized case.

3. CONCLUSION:

THE novel contribution of this research is that after a thorough review of all the available metrics, indicators and tools; it quantifies both the inherent safety and inherent occupational health for processes at the same time based on the information available at the early design stage. Sustainability impacts for both inherent safety and inherent occupational health can be measured through the retrofitted SUSTAINABILITY EVALUATOR. This measured value aids the engineer in having a quantitative number to use in deciding the sustainability impact of a process for safety and health. It is important to note that economic and environmental sustainability are not the direct concerns of this research but the methodology proposed here may easily amalgamable with the other two dimensions of sustainability for any future research. The proposed tool can be used to optimize a base case process by detecting the parameters by sensitivity analysis. The impact assessment tool is also useful in comparing processes and selecting the best option which has a more efficient reaction process, is safer as less toxic chemicals and less hazardous equipment is present in the process and less wastes to be generated in the process.

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