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An Empirical Study to Scrutinize the Interplay between Safety and Sustainable Production Performance in the Context of Chemical Industry

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Abstract – **The chemical industry is a fundamental component of how countries function. Despite its importance, less consideration has seemingly been given to the roles of safety in sustainable production. This paper reports an ongoing study to scrutinize the relationship between safety performance and sustainable production performance. The underlying foundation of the empirical study is a conceptual framework developed from a Systematic Literature Review (SLR). Five propositions from the conceptual framework would be verified with practitioners in the industry. Nine companies were interviewed, and cross-case analysis was then performed. Preliminary findings suggested that out of the five propositions from the framework, the first three are found consistent with the framework, hence the extant literature. Our future work will continue to corroborate the other two propositions.**

Keywords – **chemical industry, safety performance, semi-structured interview, sustainable production performance, conceptual framework.**

I. INTRODUCTION

Sustainable production focuses on the raw material extraction and other natural resources used in the production processes, production throughputs, and the waste generated during the production cycles [1]. Sustainable production systems strive for emission and pollution prevention, often by combining the use of renewable energy [2]. The advantages are not only in terms of environmental, but also financial, including cost savings, enhanced product quality, and healthier working environments. Achieving sustainable production thus remains an important goal for modern industry sectors [3, 4].

The chemical industry is an industrial sector that is essential in many countries, making it critical for both the global economy and the well-being of the society [5]. However, these tremendous contributions to the global economy and society's well-being could have a severe consequence to both the environment and human health and safety [6]. Despite the efforts to promote sustainable production, most have been focused on financial rewards and have neglected safety, resulting in a reduction in safety in many cases [6]. An industry is not totally sustainable simply because it is commercially viable; it must also be ecologically friendly and socially responsible [2]. Of the three pillars of sustainability, the social pillar is often the most disregarded [5]. The environment, as well as worker health and safety, are indicators of the social pillar, which the chemical industry has often struggled to as part of its sustainable production process.

Many incidents have demonstrated the lack of safety harms both the economic and environmental pillars of sustainability. Therefore, there is a greater need to understand the impacts of safety on sustainable production, and how exactly safety can influence sustainable production performance, particularly in the chemical industry. Additionally, the characteristics of the chemical industry seemingly play a role in influencing the relationship between safety and sustainable production performance; but this needs to be validated.

We have conducted a systematic literature review (SLR) and performed a thematic analysis to unravel the relationship mechanisms between safety performance and sustainable production performance [7]. The output of the SLR was a conceptual framework that formalizes the relationships between safety and sustainable production performance in the context of chemical industry.

This paper reports an ongoing empirical study to test the applicability of the framework, involving nine companies within the chemical industry sector to better understand the extent to which the propositions in the framework have been reflected in practice.

II. LITERATURE REVIEW

A. *Sustainable Production and Indicators*

The Lowell Centre for Sustainable Production (LCSP) describes sustainable production as the development of products and services by processes and procedures that are: pollution free; energy and natural resource efficient; economically viable; secure and safe for workers, communities and consumers; and socially and creatively beneficial for all working [8] [9]. To help companies measuring their sustainable production performance, LCSP developed Indicators of sustainable production (ISPs) [9] and proposed to categorized ISPs into two: 1) core indicators, which are shared by every type of companies, and 2) supplemental indicators, which can be different from company to company depending on their type of product. A set of commonly proposed core indicators are, for instance, energy and material use, natural environment, workers' health and safety, economic viability, community development and product [8].

B. Safety and Chemical Industry

The US Agency for Healthcare Research and Quality defines safety as the 'freedom from accidental injury'. The American National Standards Institute similarly defines safety as 'freedom from unacceptable risk'. Consequently, safety goals are usually defined in terms of a reduction in the measured outcomes over a given period of time.

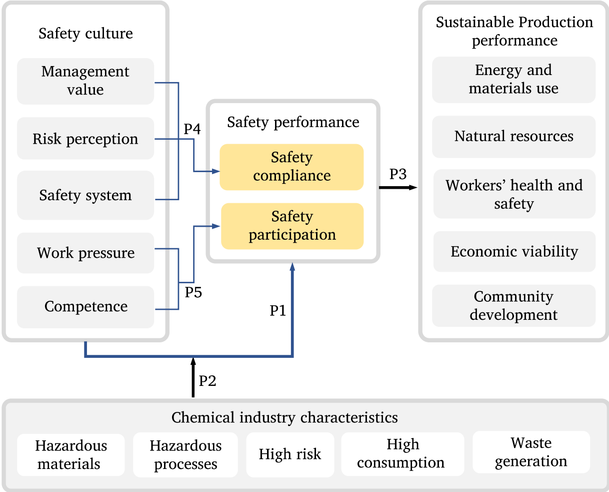
Started in 1980s and became more intense in 1990s, active work was under way on developing the legislation and risk assessments related to chemical management by European countries, industry, environmental groups, NGOs and the academics. Some well-known cases of harmful substances in products have led to increased awareness and adherence to safety regulation. Currently, there are tens of thousands of chemicals in the European market that have not been assessed and regulated. Continuous exposure to those chemicals is dangerous and can potentially be catastrophic to the health of both humans and the environment [10].

C. Safety and Sustainable Production Performance

Linking safety with sustainability is not new. Many studies have shown the importance of safety in promoting sustainable development. Reference [11] argued that improving organizations' health and safety condition will increase the achievement of sustainable development. Reference [12] reviewed the Chernobyl accident and concluded that to ensure a sustainable energy system, an organization's safety culture needs to be regarded as the most important. Noticing that the latest development to achieve sustainability may bring regarding new unknown risk, a new framework for risk assessment that can be used for creating sustainability-related designs was developed [13]. Safety and sustainability are arguably closely linked [14], as safety can offer operationalization for sustainability and both fields share the same pillars, i.e. economic, environmental, and social.

III. METHODOLOGY

This study aims to investigate the validity of a conceptual framework produced from a systematic literature review (Fig. 1). To explore the mechanisms underlying the relationship between safety performance and sustainable production performance, the study cannot depend upon measurable objective data available through quantitative methods. A mechanism is challenging to quantify as the measures to be quantified are unknown. Since the current study is primarily explorative and does not aim to establish generalizability, qualitative data are found to be suitable for this study [15].



P1 – P5: Proposition 1 – Proposition 5

Fig. 1. Conceptual Framework of Safety-Sustainable Production Performance

Multiple-case studies are desirable in circumstances when the intent of the research is exploration, description, theory building, or theory testing. Multiple-case designs allow for comparative cross-case analysis and the extension of the theory. The cross-case analysis allows the researcher to find patterns between the cases, indicating causal mechanisms [16]. Multiple-case study is chosen for this study in order to explore the phenomenon further and compare various companies. This research will focus on companies in the chemical industry that have high risk, such as those for which safety is an important issue, and also regards sustainability as an important objective. Overall, among those companies that were found to fit the criteria, nine responded to the initial approach and agreed to participate in the study. Among those nine companies, two were included as a pilot study, and the rest were included in the main data collection. Table I shows the profile of main cases.

Semi-structured interviews were conducted to those companies. Interview themes and guiding questions were developed based on the conceptual framework. Each interview lasted between 45-60 minute and was conducted online using Zoom. The recordings were then transcribed using sonix.ai.

The next step in the data analysis was to develop an *a priori* set of codes. Using the conceptual framework as the context, four themes were set: safety culture, industrial characteristics, safety performance and sustainable production performance. Those four themes were level 0 codes. Subthemes were then developed for each of the four themes. These subthemes were level 1 codes. Finally, to capture responses from the interviewees in more detail, level 2 codes were then developed for each subtheme and were then used as the final set of codes.

TABLE I
THE PROFILES OF THE CASE COMPANIES

Cases	Type of Chemical Industry	Main product	Scope of Business	Number of Workers
Alpha	Multi-purpose Plastics	Purified terephthalic acid and polyethylene terephthalate	Nationwide	385
Beta	Petro-chemical	Gasoline, diesel, and kerosene	Provincewide	100
Delta	Petro-chemical	Base oil	Provincewide	130
Epsilon	Pharmacy	Herbal medicines	Nationwide	4,700
Gamma	Agro-chemical	Fertilizer	Nationwide	1,100
Omega	Petro-chemical	Gasoline, diesel and kerosene	Nationwide	10,000
Sigma	Petro-chemical	Hydrocarbon gas	International	500
Theta	Pharmacy	Medicines and vitamins	International	500

Having developed the codes, the next step was to code the transcripts. All the interview transcripts were reviewed, and any part of the interview that was relevant to level 2 codes was tagged. Once all the interview transcripts had been coded, the relevant interview excerpts were transferred into a spreadsheet. By only including relevant excerpts, the researchers can focus on relevant data and ignore others that are not relevant.

The cross-case analysis was then conducted to analyses the patterns emerging on the cases. More specifically, the tabulated findings in every case were compared based on the key constructs of the conceptual framework. The comparison was focused on the propositions provided in the conceptual framework.

IV. FINDINGS

A. Proposition 1: Safety culture is the antecedent of safety performance. The higher the safety culture, the higher the safety performance will be

Proposition 1 postulates that safety culture is the antecedent of safety performance. As the antecedent, the presence of a safety culture is required to promote a good safety performance. This proposition also postulates that the higher the safety culture, the higher the safety performance will be. In order to test this proposition, the four possible state-pairings of safety culture and safety performance are listed: 1) good safety culture and good safety performance; 2) good safety culture and poor safety performance; 3) poor safety culture and good safety performance; and 4) poor safety culture and poor safety performance. Using state assigned to each key construct in every case presented in Table II, comparison according state-pairings are done.

The findings are consistent with proposition 1. Across seven cases, there is no case where a company has a good safety performance without the presence of a good safety culture.

B. Proposition 2: Chemical industry characteristics moderate the relationship between safety culture and safety performance. The harsher the characteristics of the chemical industry, the weaker the influence of safety culture on safety performance will be.

Proposition 2 postulates that chemical industry characteristics moderate the relationship between safety culture and safety performance. The harsher the characteristics of the chemical industry, the weaker the influence of safety culture on safety performance will be. In order to test this proposition, the two possible impacts of industrial characteristics towards safety culture’s influence on safety performance are listed: Industrial characteristics affect safety culture influence on safety performance and Industrial characteristics do not affect safety culture influence on safety performance. Comparison according those state-pairings are done according to the state listed in Table II.

The finding shows that the real situation in industry is fairly consistent with the proposition. The industrial characteristics of Alpha, Beta, Delta, Gamma, Omega and Sigma shows indications of affecting the influence of safety culture on safety performance. Epsilon is the only case that shows a contrasting result.

C. Proposition 3: Safety performance directly influences sustainable production performance. The higher the safety performance, the higher the sustainable production performance will be.

Proposition 3 postulates that safety performance directly influences sustainable production performance, and the higher the safety performance, the higher the sustainable production performance will be. In order to test this proposition, the four possible state-pairings of safety performance and sustainable production performance are listed: good safety performance and good sustainable production performance; good safety performance and poor sustainable production performance; poor safety performance and good sustainable production performance; and poor safety performance and poor sustainable production performance. Comparison according those state-pairings are done according to the state listed in Table II.

The findings are consistent with proposition 3. In every case, safety performance has a direct influence on the sustainable production performance. In Beta, Epsilon and Sigma, which have good safety performance, their sustainable production performance is also good. In contrast, Alpha, Delta, Gamma and Omega have poor safety performance. In those companies, their sustainable production performance is also poor.

D. Proposition 4: Management value, risk perception, and safety systems are the antecedents of safety compliance.

Proposition 4 postulates that management value, risk perception, and safety systems are the antecedents of safety compliance. This proposition implies that good safety compliance cannot be achieved without good management value, risk perception, and safety systems. In order to test this proposition, the four possible state-pairings of construct management value and safety compliance are listed: good management value and good safety compliance; good management value and poor safety compliance; poor management value and good safety compliance; and poor management value and poor safety compliance. The state-pairings for the other two constructs are listed in similar manner. Comparison of the cases according to the state-pairings are listed in Table II.

For construct management value, the findings are fairly consistent with proposition 4. Alpha, Beta Delta, Epsilon and Sigma have good safety compliance and good management value as the antecedent. Omega is the only case where they have good safety compliance without the presence of good management value.

However, the finding for construct risk perception shows inconsistency with proposition 4. There are only four cases; Beta, Epsilon, Gamma and Sigma that are in line with the proposition. Alpha and Omega have good safety compliance without having good risk perception. Lastly, Delta does not have good safety compliance, despite having good risk perception, making it difficult to draw any conclusions.

The comparison for construct safety system shows more consistency with proposition 4 than the previous comparison. Alpha, Beta, Epsilon, and Sigma have good safety compliance and good safety system as the antecedent. Gamma does not have a good safety system, resulting in poor safety compliance. Omega is the only case with the opposite result, while Delta does not have good safety compliance, despite having a good safety system.

E. Proposition 5: Work pressure and competence are the antecedents of safety participation.

Proposition 5 postulates that work pressure and competence are the antecedents of safety participation. This proposition implies that good safety participation cannot be achieved without good work pressure and good competence. In order to test this proposition, the four possible state-pairings of construct work pressure and safety participation are listed: good work pressure and good safety participation; good work pressure and poor safety participation; poor work pressure and good safety participation; and poor work pressure and poor safety participation. The state-pairings for construct competence are listed similarly. Comparison according those state-pairings are done according to the state listed in Table II.

The findings for construct work pressure are fairly consistent with proposition 5. Work pressure at Beta and Sigma is more ideal for workers, resulting in good safety participation. Alpha, Delta and Gamma have high work pressure, followed by poor safety participation. Epsilon is the only case with an opposite result to proposition 5.

In the comparison for construct competence, there is no result that opposes proposition 5. Beta, Delta, Epsilon and Sigma are all in line with the proposition. Alpha, Gamma and Omega all have good workers' competence, but this is not reflected by a good safety participation, thus no conclusion can be drawn from these three cases.

TABLE II
THE STATE ASSIGNED TO EACH KEY CONSTRUCT IN EVERY CASE

Key Construct	Alpha	Beta	Delta	Epsilon	Gamma	Omega	Sigma
Industrial Characteristics	Very high risk	Very high risk	Very high risk	High risk	Very high risk	Very high risk	Very high risk
Management Value	Good	Very good	Poor	Good	Good	Poor	Very good
Risk Perception	Poor	Good	Good	Good	Poor	Poor	Good
Safety System	Good	Good	Good	Good	Poor	Poor	Very good
Work Pressure	Poor	Good	Poor	Poor	Poor	Good	Good
Competence	Good	Very good	Poor	Good	Good	Good	Very good
Safety Culture	Good	Good	Poor	Good	Poor	Poor	Very good
Safety Compliance	Good	Good	Poor	Good	Poor	Good	Good
Safety Participation	Poor	Good	Poor	Good	Poor	Poor	Good
Safety Performance	Poor	Good	Poor	Good	Poor	Poor	Good
Sustainable Production Performance	Poor	Good	Poor	Good	Poor	Poor	Good

V. CONCLUSION

This study was conducted to better understand the extent to which the propositions within the framework have been reflected in practice. The framework itself formalizes the relationships between safety and the sustainable production performance, set within the chemical industry.

To test the applicability of the framework, empirical data from nine case companies collected, and the findings can be summarized as follows:

1. Our empirical data are consistent with propositions 1, 2 and 3.
2. Proposition 4 combines three constructs (management value, risk perception and safety system) and connect them to safety compliance. While the empirical data for construct management value are consistent with the proposition, there are some inconsistencies with construct risk perception and safety system.
3. Proposition 5 combines two constructs (work pressure and competence) and connect them to safety participation. Construct work pressure is fairly consistent with the proposition, with only one case showing the opposing result. While there is no case with contrasting results for construct competence, only three cases strongly support the proposition. In almost half of the cases, there is no conclusion to be drawn.

The findings from the case study suggested that propositions 1, 2 and 3 are consistent with the industrial practice. However, there are some indications that propositions 4 and 5 do not comply. As a result, there is a need to revise the conceptual framework to better reflect the industrial practice. Further work and more data are needed to confirm these.

There are two limitations in this study. So far, we only analyzed the data from nine case companies. Second, in order to follow-up, cross check or clarify the initial findings, we consider the second round of interview to each company, targeting different informants.

Future work will also be focused on designing a quantitative research protocol, perhaps using survey or simulation study akin to [17], with an intention to provide a scenario analysis mechanism. We foresee this as one of the worthwhile efforts to further validate our propositions.

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