Assessment of Safety and Health in the Tea Industry of Barak Valley, Assam: A Fuzzy Logic Approach

Rajat Gupta

Sanjoy Kumar Dey

Department of Mechanical Engineering, National Institute of Technology, Silchar, Assam, India

Traditional safety and health system measurement procedures, practiced in various industries produce qualitative results with a degree of uncertainty. This paper presents a fuzzy-logic-based approach to developing a fuzzy model for assessing the safety and health status in the tea industry. For this, the overall safety and health status at a tea estate has been considered as a function of 4 inputs: occupational safety, occupational health, behavioral safety and competency. A set of fuzzy rules based on expert human judgment has been used to correlate different fuzzy inputs and output. Fuzzy set operations are used to calculate the safety and health status of the tea industry. Application of the developed model at a tea estate showed that the safety and health status belongs to the fuzzy class of good *with a crisp value of 7.2.*

vagueness   fuzziness   safety   fuzzy set

1. INTRODUCTION

Safety and health are the key concern of any business. Safety and productivity are two sides of the same coin. Even though the tea industry in Assam, India, provides livelihood to over one million people directly and is a significant source of foreign exchange to the state exchequer, it faces challenges in ensuring workplace safety to its workers mainly for two reasons. Firstly, its management's erroneous mindset of accepting safety as a liability to the business and, secondly, the lack of safety awareness amongst the workers [1]. Statistics of accidents reveals that every year numerous accidents take place in the tea industry of Assam causing physical injury, disability, property loss and loss of production time. What really matters is that every year fatal accidents take place at an alarming rate claiming human lives. So, there is an urgent need to investigate the safety and health status of the tea industry to explore the underlying flaws with a view to improve them. The endeavor is very important in the context of poor performance of the tea industry in overcoming the challenges offered by newer global players in the field. However, to improve the safety and health status of the tea industry, it is necessary to measure it first. Traditional systems of assessing the safety and health status such as safety auditing produce qualitative results. Moreover, they are time consuming and involve numerous professionals and documents; they are primarily designed to cater to the needs of industries that pose a major accident hazard. Though the tea industry is not categorized as a major accident hazard in India, it poses a significant safety and health hazard to its workers. So, a comprehensive and quantitative measurement approach reflecting the true picture of the safety and health status of the tea industry is necessary. With this backdrop, the paper presents a safety and health status assessment model based on fuzzy logic. It is specific to the tea industry and it overcomes the fuzziness in the current safety and health assessments.

Safety and health status assessment involves assessing something hypothetical defined as safety and health, which is defined in terms of natural language as *poor*, *good*, *very good*, etc. Such assessment, whether qualitative or quantified, requires the analyst's judgment, expert knowledge and experience. Quantification of the safety and health status is subject to uncertainty for many reasons including difficulties in defining the various factors contributing to the safety and health in an industry and the mathematics of combining them. Fuzziness and vagueness in the terms involved remain crucial.

Brief Literature Review

A study of accidents in 2004–2009 showed that every year numerous accidents took place in the tea industry of Assam, including fatal accidents, indicating a poor standard of safety and health in this industry [1]. Safety assessment based on conventional tools (e.g., probability risk assessment) may not be well suited for dealing with systems with a high level of uncertainty, particularly in the feasibility and concept design stages of a maritime or offshore system. By contrast, a safety model based on a fuzzy logic approach with IF–THEN rules can model qualitative aspects of human knowledge and reasoning processes without quantitative analyses. A fuzzy-logic-based approach may be more appropriate for risk analyses in the initial design stages. It provides a tool for working directly with linguistic terms common in safety assessment. Fuzzy logic is used to develop and represent linguistic variables to model risk levels subjectively. The variables are than quantified using fuzzy sets [2]. Wang, Tang and Sen presented a new methodology for safety analysis and synthesis of a complex engineering system with a structure capable of being decomposed into a hierarchy of levels [3]. In this methodology, the fuzzy set theory is used to describe each failure event and an evidential reasoning approach is then employed to synthesize the information thus produced to assess the safety of the whole system. Howard and Seraji developed a fuzzy rule based a safety index that quantifies the ease-of-landing a spacecraft on a planetary surface based on sensor derived measurements of terrain characteristics [4]. The proposed representation of terrain safety incorporated an intuitive, linguistic approach to expressing terrain characteristics that was robust with respect to imprecision and uncertainty in the sensor measurements. Directive 1999/92/EC regulates the safety and health of workers potentially at risk from explosive atmosphere: explosion risk must be assessed and mitigated properly [5]. For that purpose, Markowski, Mannan, Kotynia, et al. used the explosion layer protection analysis, which made it possible to carry out semiquantitative explosion risk assessment in process plants with explosive atmospheres [6]. They used a fuzzy logic system to overcome the problem of uncertainty and receive more detail quantitative results. Hayward and Davidson used fuzzy logic as a modeling method well suited for the control of complex and nonlinear systems [7]. They illustrated some of the power of fuzzy logic through a simple control example. Mahant developed a novel approach to overcome the fuzziness in traditional risk assessment, and a risk assessment model using fuzzy logic for major hazards [8]. The likelihood of the occurrence of incidents is regarded as a function of the robustness of a safety management system. Fuzzy set operations combine the severity of consequences and the likelihood of occurrence to calculate risk. Oke, Johnson, Popoola, et al. applied a fuzzy logic control model to profitability in a case study of the plastic recycling industry of Nigeria [9]. They studied the profitability components of that industry to develop a model framework and applied a fuzzy logic control model to the framework. Fuzzy set approaches always seem to be most appropriate when modeling human knowledge is necessary [10]. Karwowski and Mital discussed potential applications of a fuzzy set theory to risk analysis in industrial safety engineering [11]. Vagueness and imprecision in mathematical quantification of risk were equated with fuzziness rather than randomness. The concept of risk evaluation, using linguistic representation of the likelihood of the occurrence of a hazardous event, exposure and possible consequences of that event, was proposed. The approximate reasoning technique based on fuzzy logic is used to derive fuzzy val-

ues of risk. Karwowski and Mital [12], Karwowski [13] and Grobelny, Karwowski and Zurda [14] did similar work. Based on this literature survey, the objective of the present research was set as follows:

- to develop a safety and health system assessment model based on a fuzzy logic approach applicable to the tea industry;
- to use the developed model in the tea industry in a case study.

2. SAFETY ASSESSMENT

A safety audit has been the management's important tool for evaluating the effectiveness of a factory's safety and health system since 1970. Large organizations in the developed countries have used it. Initially, audits were based on financial models because these were a structure well known to all giant corporations. After a series of industrial disasters, e.g., in Bhopal, Flixborough, San Juanico, Chernobyl, Seveso, the objectivity of the safety assessment system was recognized. Safety audits have now been introduced in many organizations to evaluate the strength and weakness of safety and health systems. The effectiveness of those systems cannot be judged unless they are systematically assessed. In India, the Factories Act, 1948[1] is the principal regulation on safety and health in factories. It focuses on workplace safety and health performance in compliance with various attributes of safety, health, welfare, etc. In this paper, the safety and health status of a tea estate is the result of compliance with all the factors in the Factories Act. The implication of this new approach is that the safety and health system is a function of the compliance level of different parameters contributing to safety and health as per the Factories Act.

Any simple measurement of performance in terms of accident frequency rate or severity rate is not a reliable guide to the safety performance of an undertaking. There is no co-relation between such measurements and working conditions, injury potential or severity of injuries that have occurred. A need exists for a better assessment to control foreseeable risk.

3. FUZZY LOGIC

Fuzziness describes the ambiguity of an event. Logic for humans is a quantitative way to develop a reasoning process that can be replicated and manipulated with mathematical precepts. The interest in logic is the study of truth in logical propositions. In classical predicate logic, this truth is binary: a proposition is either true or false. From this perspective, fuzzy logic is a method to formalize the human capacity for imprecise or approximate reasoning. Such reasoning represents the human ability to reason approximately and judge under uncertainty. In fuzzy logic, all truths are partial or approximate. In this sense, this reasoning has also been termed interpolative reasoning, where the process of interpolating between the binary extremes of *true* and *false* is represented by the ability of fuzzy logic to encapsulate partial truths. The subjectivity that exists in fuzzy modeling is a blessing. The vagueness present in the definition of terms is consistent with the information contained in the conditional rules developed by the engineer when observing some complex process. Even though the set of linguistic variables and their meanings are compatible and consistent with the set of conditional rules used, the overall outcome of the qualitative process is translated into objective and quantified results. Fuzzy mathematical tools and the calculus of fuzzy IF–THEN rules provide a useful paradigm for the automation and implementation of extensive body of human knowledge, which is not embodied in the quantitative modeling process. These mathematical tools provide a means of sharing, communicating and transferring this human subjective knowledge of systems and processes. The use of fuzzy logic is justified because it is tolerant of imprecisely defined data; it can model nonlinear systems or processes of high degree of complexity; it is able to build on human expertise [8].

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[1] http://www.ilo.org/dyn/travail/docs/663/

Equations 1 and 2 express a fuzzy union and an intersection of two fuzzy sets, respectively.

$$\mu_{A\cup B}(x) = \max[\mu_A(x),\mu_B(x)], \quad (1)$$

$$\mu_{A\cap B}(x) = \min[\mu_A(x),\mu_B(x)]. \quad (2)$$

Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number. Several methods for defuzzification are used in practice, including the centroid, maximum, mean of maxima, height and modified height defuzzifier. The centroid method is the most popular defuzzification method; it calculates and returns the center of gravity of the aggregated fuzzy set.

4. SAFETY MODEL

4.1. Principles

The fuzzy safety and health status model for the tea industry is built on three principles.

- The level of safety and health in the tea industry is a function of four noninteractive input levels, i.e., occupational safety (OS), occupational health (OH), behavioral safety (BS) and competency (C), and these four inputs encapsulate all elements of safety and health in the tea industry. The safety and health elements are considered as per requirements of the provisions of the Factories Act, 1948, which are relevant to cut–tear–curl (CTC) tea manufacturing.
- Gaps in the level of any safety element can cause harmful events resulting in injury, loss of property or loss of production time.
- The safety and health status is the output.

4.2. Methodology

Constructing a fuzzy model for measuring safety and health in the tea industry involves several steps.

- All factors affecting safety and health in the tea industry are identified from the Factories Act, 1948, and listed under four broad

categories of OS, OH, BS and C. These are treated as inputs into the safety and health system of the tea industry under consideration. Tables 1–4 describe models for assessing the level or status of these four inputs on a scale of 0–10. In these proposed models, the numerical values of weights, assigned to each safety element, are based on the relative significance of the elements in causing harmful events due to their poor standard or nonexistence and depend on the evaluator's subjective judgment and experience. The sum of all weights in a particular category of inputs is one. Rating is assigned to each element depending again on the evaluator's expert human knowledge and experience regarding the quality of preventive measures for that element after examining it from all relevant aspects. The tables for each input are filled with values from Rosekandi tea estate, in Assam, India, where a case study was undertaken to use the fuzzy safety and health assessment model.

- Valid ranges of four input variables (OS, OH, BS and C) are considered and divided into three partitions or triangular fuzzy sets. These fuzzy sets are designated with linguistic values of *poor*, *good* and *excellent*. The boundaries of these fuzzy sets overlap or, in other words, the sets do not have clear or crisp boundaries. The degree of belongingness of the values of a variable to any fuzzy class is called the degree of membership. Figure 1 shows the fuzzification of all these inputs and the output into triangular fuzzy sets. The fuzzy sets for each input are categorized as follows:

  - *Poor* describes a system with no or poor evidence of safety measures such as unguarded or inadequately guarded moving machines, belts, pulleys, uncertified lifting tackles, chain pulleys, pressure vessels, well defined safety policy, critical safety procedures, safety training, etc. On a scale of 0–10, most independent assessors would give the system an overall score under 5 and consider it poor.
  - *Good* describes a system with a declared safety policy, engineered protection system, high level compliance with statutory safety

regulations, normal safety training and procedures, etc. On a scale of 1–10, most independent assessors would give the system an overall score of 4–8 and consider it good.

- *Excellent* describes a system with evidence of a very high level of safety procedures, automated guarding, high level safety training, highly skilled workers, absolute compliance with statutory regulations, etc. On a scale of 1–10, most independent assessors would give the system an overall score over 8 and consider it excellent.

- Safety and health status is the output; it is defined in five fuzzy classes on a scale of 0–10: *very poor* = high probability of occurring accidents with fatality; *poor* = possibility of fatality is but high possibility acute physical injury/harm, property damage; *average* = possibility of fatality and acute physical injury is virtually nil but possibility minor accidents and property damage remains

high; *good* = there is no possibility of fatality or serious accidents but there is low possibility of minor injury and property damage; *very good* = there is virtually no risk of accident of any kind. Figure 2 shows fuzzification of the safety and health status (output).

- Expert knowledge is used to characterize inputs and output and to connect inputs and output with a set of inference rules with IF–THEN statements.

- Mamdani inference methodology is used to combine inputs and output.

- The fuzzy output set is then defuzzified to arrive at a crisp (scalar) value with the help of centroid method, which signifies the level of safety and health in the tea industry.

In reality, there are no limits to the number of inputs, number of output, number of rules or the number of classes used to define the range of variable. The modeling process is made convenient by proprietary software [8].

TABLE 1. Assessment of Occupational Safety at Rosekandi Tea Estate

Elements of Occupational Safety	Weight	Rating (%)	Weighted Rate	Score
Guarding machines	0.20	60	12	1.2
Electrical safety	0.20	40	8	0.8
Fire safety	0.10	50	5	0.5
Walkways, staircases	0.10	70	7	0.7
Lifting tackles, chain pulleys and pressure vessels	0.05	100	5	0.5
Procedures	0.10	70	7	0.7
Personal protective equipment	0.10	60	6	0.6
Boiler safety	0.05	100	5	0.5
Building safety	0.05	80	4	0.4
Machine safety	0.05	80	4	0.4
total				6.3

Notes. Score = weighted rate/10.

TABLE 2. Assessment of Occupational Health at Rosekandi Tea Estate

Elements of Occupational Health	Weight	Rating (%)	Weighted Rate	Score
Ergonomics	0.3	70	21.0	2.10
Noise	0.2	60	12.0	1.20
Ventilation and temperature	0.2	80	16.0	1.60
Fiber and dust removal system	0.1	40	4.0	0.40
Housekeeping	0.1	95	9.5	0.95
Drinking water	0.1	100	10.0	1.00
total				7.25

Notes. Score = weighted rate/10.

TABLE 3. Assessment of Behavioral Safety at Rosekandi Tea Estate

Elements of Behavioral Safety	Weight	Rating (%)	Weighted Rate	Score
Worker attitude	0.3	70	21	2.10
Worker morale	0.3	60	18	1.80
Management commitment and co-operation	0.2	80	16	1.60
Compliance with statutory laws	0.1	90	9	0.90
Safety policy and planning	0.1	70	7	0.70
total				7.10

Notes. Score = weighted rate/10.

TABLE 4. Assessment of Competency at Rosekandi Tea Estate

Elements of Competency	Weight	Rating (%)	Weighted Rate	Score
Skill	0.3	85	25.5	2.55
Training	0.5	60	30.0	3.00
Safety information	0.2	60	12.0	1.20
total				6.75

Notes. Score = weighted rate/10.

4.3. Case Study

A case study was undertaken at Rosekandi tea estate in the Cachar district of Assam, India, to use the developed model to measure the safety and health status of the estate. The estate employs ~150 workers in each of three work shifts per day; it manufactures ~1.4 million kilograms of black tea annually. The tea processing operations can be divided into five phases: withering, CTC, fermentation, drying and sorting. Figure 3 is a block diagram of the tea manufacturing process at Rosekandi tea estate. In this safety assessment model, the four inputs, i.e., OS, OH, BS and C, are assessed according to the models in Tables 1–4.

The assignment of weight and ratings is made as per justification in the first step in section 4.2. There are 12 inference rules, which relate inputs and output:

1. IF OS is *poor* AND OH is *poor* AND BS is *poor* AND C is *poor* THEN Safety is *very poor*.
2. IF OS is *poor* AND OH is *poor* AND BS is *poor* AND C is *good* THEN Safety is *poor*.
3. IF OS is *poor* AND OH is *good* AND BS is *good* AND C is *good* THEN Safety is *average*.
4. IF OS is *good* AND OH is *good* AND BS is *good* AND C is *good* THEN Safety is *good*.
5. IF OS is *good* AND OH is *good* AND BS is *good* AND C is *poor* THEN Safety is *good*.
6. IF OS is *excellent* AND OH is *excellent* AND BS is *excellent* AND C is *excellent* THEN Safety is *very good*.
7. IF OS is *excellent* AND OH is *good* AND BS is *poor* AND C is *good* THEN Safety is *good*.
8. IF OS is *good* AND OH is *good* AND BS is *excellent* AND C is *poor* THEN Safety is *good*.
9. IF OS is *poor* AND OH is *excellent* AND BS is *good* AND C is *poor* THEN Safety is *average*.
10. IF OS is *excellent* AND OH is *excellent* AND BS is *good* AND C is *poor* THEN Safety is *average*.
11. IF OS is *excellent* AND OH is *good* AND BS is *good* AND C is *excellent* THEN Safety is *good*.
12. IF OS is *good* AND OH is *excellent* AND BS is *excellent* AND C is *good* THEN Safety is *good*.

For the case study, Figure 4 shows a simplified explanation of the application of rules 4 and 6 from this list. On a scale of 1–10, the scores obtained with expert human judgment for OS, OH, BS and C are 6.3, 7.25, 7.1 and 6.75, respectively. For these scores, rules 4 and 6 are invoked. AND means an intersection of fuzzy sets and gives the fuzzy output sets on the right side of Figure 4. A union of two output sets gives the aggregated output at the bottom of Figure 4. The fuzzy output is defuzzified with the centroid
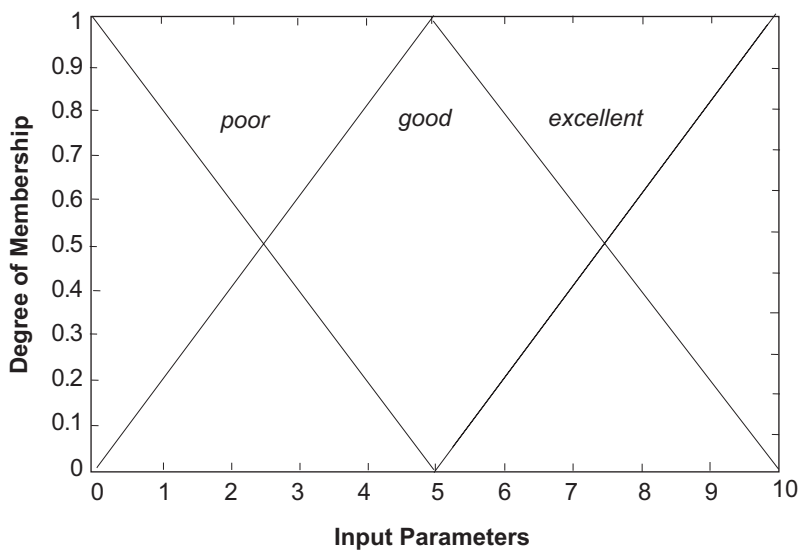
Figure 1. Range and classes of occupational safety (OS), occupational health (OH), behavioral safety (BS) and competency (C). *Notes.* Input parameters = OS, OH, BS or C.
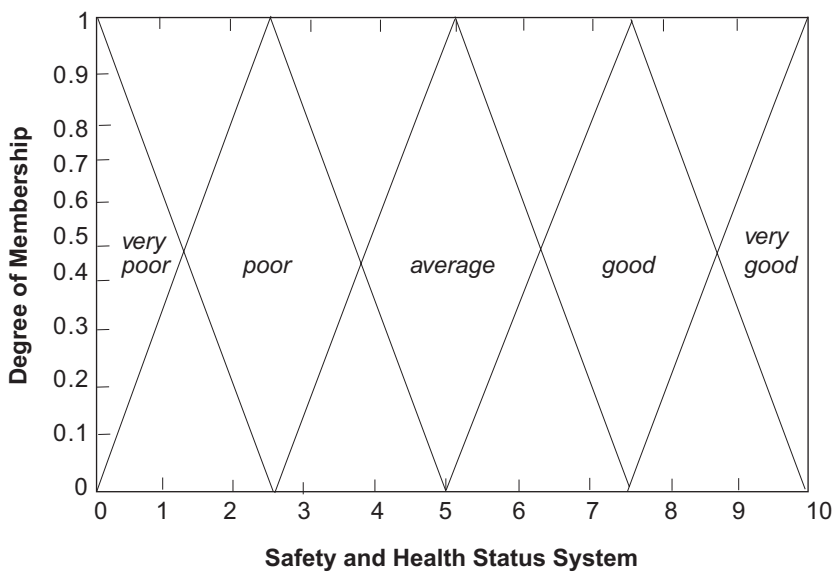

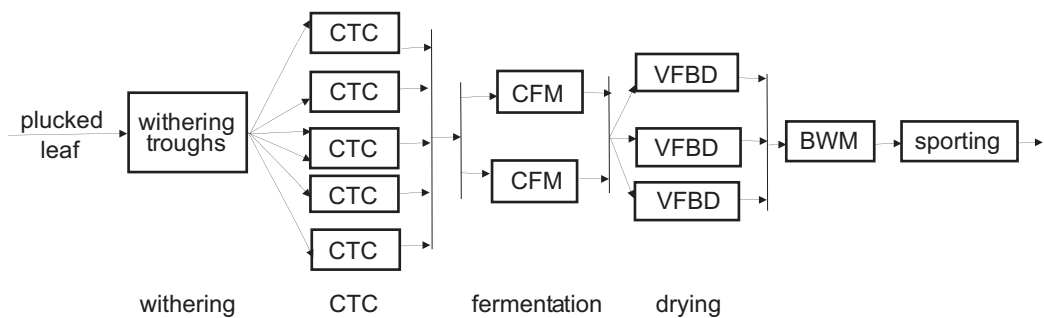**Figure 2. Fuzzification of safety and health status (output).**

Figure 3. Tea manufacturing processes at Rosekandi tea estate. *Notes.* CTC = cut–tear–curl, CFM = continuous fermenting machine, VFBD = vibratory fluidized bed dryer, BWM = batch weighing machine.
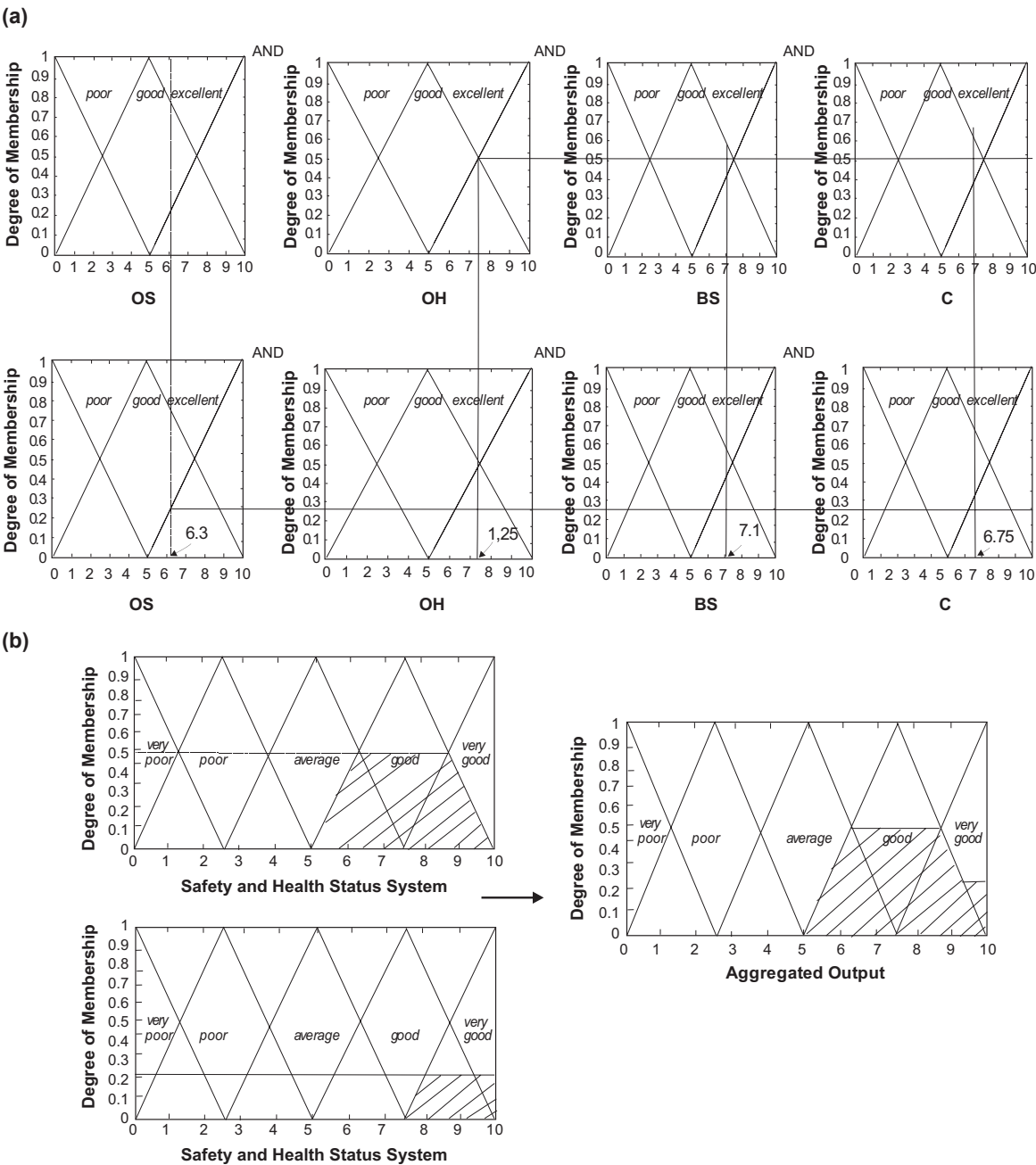
(a)

(b)

Figure 4. Assessment of safety and health status at Rosekandi tea estate: (a) rule 4, (b) rule 6.
Notes. OS = occupational safety, OH = occupational health, BS = behavioral safety, C = competency.

method giving the crisp value of the output as 7.2, the value of safety and health at Rosekandi tea estate, which falls in the safety and health class of *good* with a high membership value.

5. CONCLUSION

Safety and health assessment is based on imprecisely defined inputs. Fuzzy logic methodology provides a way to characterize the imprecisely defined variables, define relationships between variables based on expert human knowledge and use them to compute results. This paper presented models for assessing assess the level of various inputs to the safety and health status in the tea industry, which was computed with fuzzy set operations. It is recommended that the management of Rosekandi tea estate undertake necessary steps to bring the level of safety and health to the class of *very good*, e.g., improve fire protection

facilities, provide training for workers, improve fiber removal systems, provide personal protective equipment. This study provided an idea about the safety and health status at one tea estate, which may be also used at other tea estates.

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