ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DEVELOPMENT OF FUZZY DECISION SUPPORT SYSTEM FOR ACCIDENT PREVENTION BASED ON WORKER CONDITIONS AND PROJECT ENVIRONMENTS

[1*]LILA AYU RATNA WINANDA, [2]ACHMAD ARIFIN, [1]TRIJOKO WAHYU ADI, [2]FAUZAN ARROFIQI, [1]NADJADJI ANWAR

[1]Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo Surabaya 60111, Indonesia

[2]Department of Biomedical Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo Surabaya 60111, Indonesia

E-mail: [*]lilawinanda@gmail.com

ABSTRACT

Complexity in construction implementation has been proven to cause fatal accidents as a result of human errors due to fatigue. Construction accidents could happen at any time and the occurrence is difficult to predict in dynamic project characteristics. There are relationships between internal (workers) and external factors (construction environments) as leading factors in the accident since the project conditions also cause fatigue. Therefore, this paper presents an integrated system through real-time monitoring, with appropriate tools to decide workers safety conditions. The purpose of the developed system is to prevent construction accidents by monitoring workers' conditions during working hours. Fuzzy-based decision-making was proposed as a real-time monitoring system based on fatigue prediction, hazard level, environment effect, and safety analysis, according to internal conditions (heart rate, body temperature, and muscle activity) and external factors (hazard zone, safety protection, working space temperature, noise level, and illumination), then added with historical safety data. Fuzzy approach was used to develop the system according to the knowledge-based from experience, database, and expertise, since high accuracy of this method in analyzing qualitative issues such as safety assessment. Software development for fuzzy decision support system application has been realized to solve the problem in the form of safety decision-making. The performance evaluation showed that the overall fuzzy system was running well. Experimental tests on the system delivered the input data and proceed to expected output, as workers' safety decisions. The results show that the varied output of workers' safety conditions could be represented in the data model with different physiological conditions. Worker performance is assessed in preparation work to observe the readiness of workers, followed by real-time monitoring on working hours, where the data is updated hourly or minute. Therefore, fuzzy decision support system is appropriate in accident prevention and part of efforts in achieving construction safety. The integration with sensor networks is needed to realize the final goal in modern safety management in construction.

Keywords: *Construction Safety Monitoring, Decision Support System, Fuzzy Decision Making.*

1. INTRODUCTION

Construction is a unique and dynamic industrial activity due to a tight schedule with high complexity caused by various resources involved. Construction activities still depend on labor as the main source of work completion. When the goal is strict, all the energy of the workers must be mobilized. However, people have limited capacity, where high demand will force workers to their ability. It leads to the weakness in health and safety problems, reflected in the highest rates of accidents in almost all countries in the world. In Indonesia, the highest accidents were caused by construction with 31.9% and increased between 5% - 10% per year. These also encourage accidents at any time during working hours, make it more difficult to predict and prevent [8, 12, 23].

Some previous studies stated that the dominant factors that caused construction accidents were unsafe actions (human errors) with almost 88%, while the others were unsafe conditions with 10%

and the act of God with 2%. Even though the unsafe conditions only contribute as much as 10% in construction accidents, the relationships with unsafe act cannot be ignored [11, 14, 17, 21].

The accidents due to human error, as much as 50% are caused by loss of balance and alertness level which is described as an initial symptom of fatigue. Through fatigue, performance degradation happened and caused the risk of accidents [8, 30]. On the other hand, measuring fatigue is not easy because it only can be approached through general symptoms of changes in physiological and psychological conditions and cannot be measured directly at the source of fatigue. The method with self-report and subjective measurement is the most widely used in previous studies related to worker fatigue [4, 6, 7, 19, 26, 31]. Fatigue assessment with subjective measurement causes discomfort for constructions worker with high mobility characteristics, due to the loss of working time to complete the checklist. Fatigue rate cannot be updated with "just a time" assessment such as a subjective measurement because fatigue is a dynamic process, the previous state will affect the current conditions and depends on the workload for workers [6]. Therefore, the real-time measurements are most appropriate through the objective assessment based on the physiological conditions of workers, since the results are closer to reality.

Based on Maurits as stated in [18], the unsafe condition comes from environment conditions of the project site such as worker's position, project's characteristics, weather, and noise. Unstable condition in high elevation, potentially causing falls from height. According to BPJS data, "falling from a height" was still the main cause of accidents with 26%. Falling from a height was determined from project characteristics which are call hazard areas. The project's characteristics of project related to the safety analysis are determined by the design of project which contains hazard points automatically. Project characteristics will produce a potential hazard such as open space, unprotected side, and hole/opening and cause a potential danger for workers with unstandardized safety protection [7, 17, 24, 25, 31]. Generally, construction operation takes in an open workplace. Therefore the environmental conditions around the site will affect the implementation of construction. Worker activities in hot weather such as sun exposure, will increase heat stress and affect the body's metabolism. Visual acuity is also impaired. Noise from construction equipment reduces concentration due to work stress and causes accidents.

In construction safety, risk means a potential accident. Generally, construction workers are affected by an excessive risk of being hurt at work. This assessment is decided by the management level. It is determined by the safety historical database such as previous project performance related to the accidents and worker health data [10].

Some efforts have been made to prevent the accident, such as regulations. However, in fact, the role of government through H&S policies has not been consistently implemented by the project manager [29]. A manual inspection system that is commonly used causes the data to be poorly organized and seems useless for accident prevention action. Meanwhile, morning briefing for workers usually only illustrates the general description of hazards without deep screenings of the physiological condition for good work preparation.

Previous studies have started the exploration of safety analysis with information technology approaches through sensing and biomechanical measurement. However, based on the existing conditions, the availability of instruments is still fragmented. It is difficult to use for construction workers with dynamic mobility, moreover, the integration of instruments is not necessarily compatible with each other and the data analysis becomes more complicated.

In the real-world, every situation is not always clearly defined. Therefore each decision-making also involves the subject of uncertainty. A decision support system will be more appropriate when the decisions are made according to human reasoning-based. As it is known in workplace safety issues, the characteristic of parameters used in the assessment is more qualitative. Since human preferences and opinions are contained of vagueness, it can be replaced by a linguistic approach to express decisions in real terms through membership functions and inference systems as a fuzzy system concept. Fuzzy system is appropriate for representing human knowledge and solving problems in decision making. The fuzzy logic approach has been used in many areas and has been proven to minimize the weakness of qualitative approaches including subjectivity, doubt, and personal judgment from experts [9, 13, 15].

As discussed previously, it is important to design a monitoring system based on physiological conditions and the environment characteristic of construction project to prevent accidents. Therefore, we propose a fuzzy decision support system as real-time monitoring for construction safety with in-

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

depth analysis focused on workers as the main resources. The novelty of this research is a real-time safety monitoring system for workers based on internal (workers condition) and external factors from projects environment for human reasoning-based decision making through a fuzzy logic approach and stated in software development. The contributions of this research consist of three parts: observing the readiness of workers in work preparation, analyzing fatigue prediction, hazard level and environment effect during working hours, and decision-making through safety analysis as an integrated safety monitoring system. A number of data models with different physiological conditions are generated to represent the output of the systems approach.

The proposed system is focused on an integrated monitoring system, realized in the development of FDSS is a software application to ascertain the solutions for accident prevention and improvement in construction workers' safety. A further topic of our research is integrating the existing systems with sensor networks to complete the whole safety system for construction workers. This analysis is part of the final goal in developing a modern safety management system related to planning, monitoring under implementation and evaluation including all related to the construction project.

2. METHODS

2.1 Flow Diagram of Safety Monitoring

Previous studies stated that construction workers accident was determined by the relationship between internal and external factors [11, 14, 17, 21, 27, 28]. Internal conditions can be measured through the physiological changes during working hours such as heart rate value, body temperature, and muscle activity as the easiest indicators for construction workers with high mobility. Construction project's characteristics as external factors (project design and environment condition) also affect the accident occurrence. To accommodate historical health data of workers and safety performance of projects, the management level can decide through health record and safety risk. Therefore the relationships for the whole safety system can be shown in the flow diagram (Figure 1).

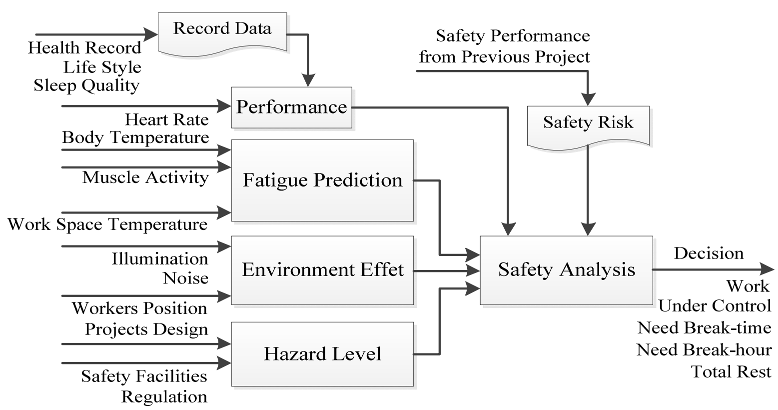


Figure 1: Flow diagram of safety analysis system

2.2 Research Framework

Based on the flow diagram, the decision support system (DSS) for worker safety monitoring was developed with two basic concepts, namely measurement of work preparation and on working hours as shown in the research framework for safety monitoring system (Figure 2). Measurement in work preparation meant checking workers' readiness and prevented worse conditions during work. When the performance was good, then the decision was "going" to work and proceed with measurement on working hours. If the performance was poor, then "stop" was recommended and the workers should take medical treatment or rest, and real-time monitoring was unnecessary.

Figure 2 also shows three steps of analysis. The first stage determined variables identification according to the flow diagram, which was used as an input data in this analysis, then followed by the development of a fuzzy system with the output divided into fatigue predictions, hazard levels, environmental effects, and safety risks. In the final stage, input data come from the output in the previous stage and then processed into construction worker safety decisions.

Journal of Theoretical and Applied Information Technology
31st December 2020. Vol.98. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

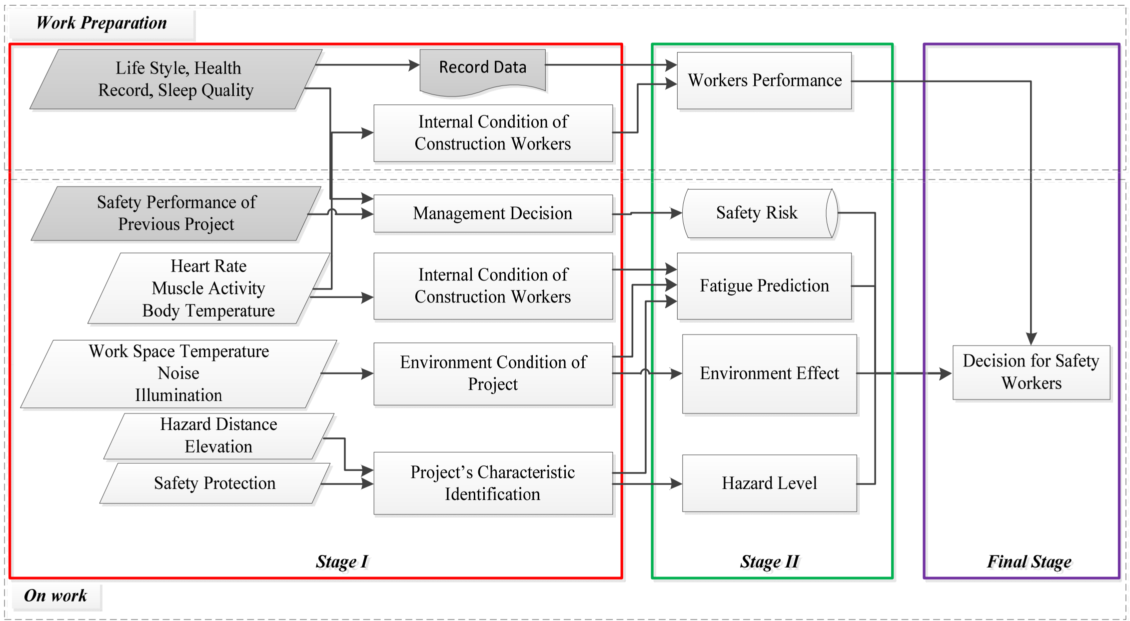


Figure 2: Research framework for safety monitoring

2.3 Methodology of the Developed Framework

2.3.1 Knowledge-based Approach

The initial step in developing a decision support system was safety monitoring of construction workers started with identifying variables. A boundary value of identified variables was traced by referring to previous research and literature studies and then discussed with experts who have more than five years of experience in construction projects and institutions related to safety and health through interviews. Fifteen data were collected from the interview process with the experts. The interviews were conducted to collect numerical data from variables related to the safety of construction workers as fuzzy input. Representation of knowledge-based approaches related to safety systems was also adapted in the analysis process to realize the output.

2.3.2 Structure model of fuzzy system

The fuzzy computation scheme was a basic tool for safety monitoring system. The fuzzy decision support system was realized in Pascal language programming. Numerical input/output variables changed into linguistic variables as represented in each membership function as fuzzification process. Then the data was processed using an inference engine in accordance with knowledge-based from expert opinions, experience, and database through fuzzy rule sets. Fuzzy inference system is a state of fuzzy rule evaluation using the functions of implication and aggregation to find output. A decision can be obtained from defuzzification mechanism by converting the fuzzy output into crisp value. In this study, the decision was used as a recommendation for safety officers and workers for implementation. To ensure the accuracy of the system, experimental computation was conducted as assessments and then the experimental simulations were conducted to observe the behaviors in the developed model [2]. The model structure of the fuzzy system for safety monitoring is illustrated in Figure 3.

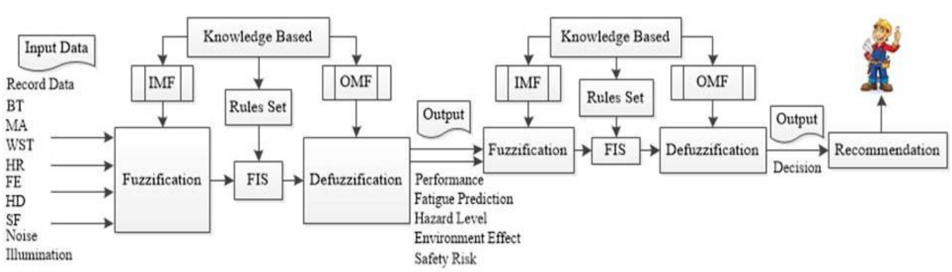
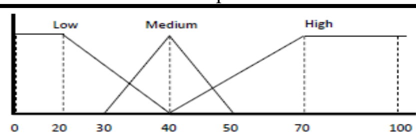
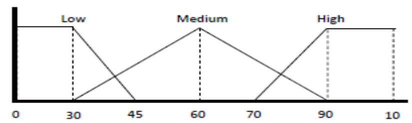
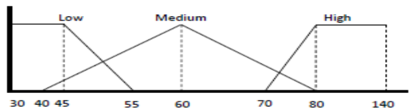
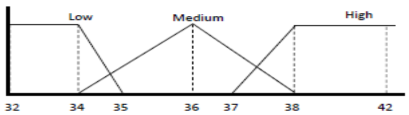
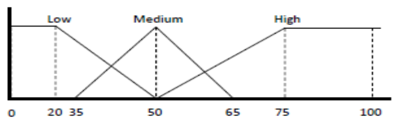
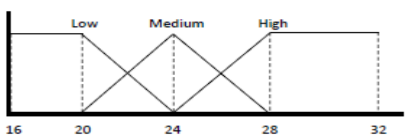
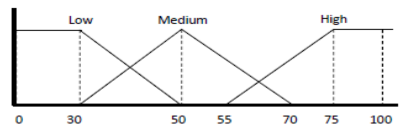
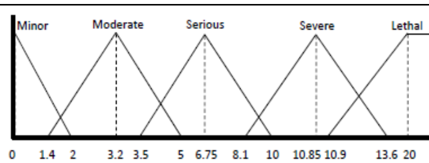
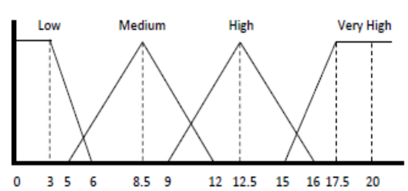
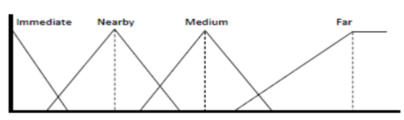
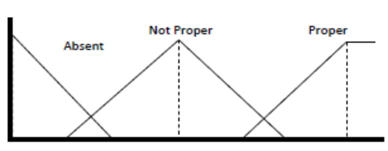
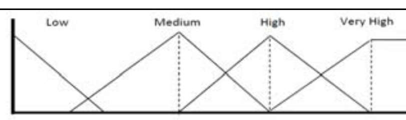
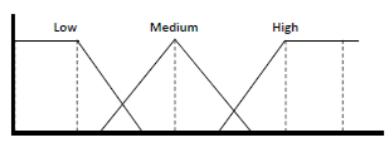
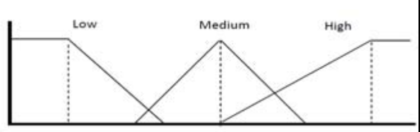


Figure 3: Structure model of fuzzy system for safety monitoring

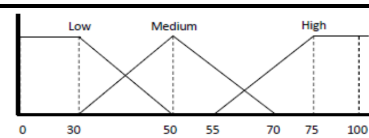
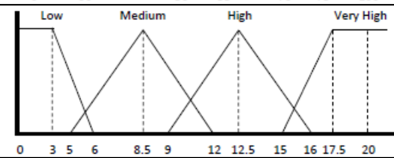
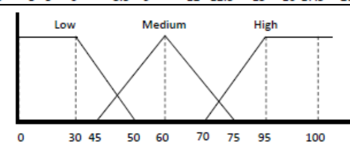
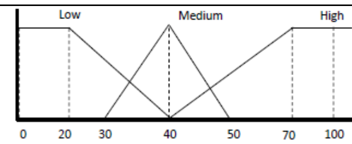
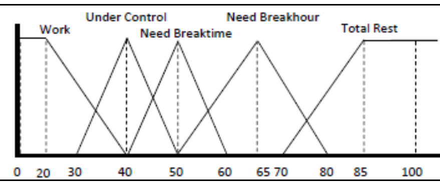
Fuzzy logic analysis begins with fuzzification by changing an exact value into the fuzzy input/linguistic variable according to its membership function. Triangular fuzzy number (TFN) was used as defined in previous studies [28]. The linguistic variables are shown in Table 1 and Table 2.

Table 1: Membership functions for stage 2

<table>
<tr><th colspan="2">Functions : Input</th><th colspan="2">Functions : Output</th></tr>
<tr><th>Variables</th><th>Membership Function</th><th>Variables</th><th>Membership Function</th></tr>
<tr><td>Record data</td><td></td><td rowspan="4">Performance</td><td rowspan="4"></td></tr>
<tr><td>Heart rate</td><td></td></tr>
<tr><td>Body temperature</td><td></td></tr>
<tr><td>Muscle activity</td><td></td></tr>
<tr><td>Working space temp.</td><td></td><td>Fatigue Prediction</td><td></td></tr>
<tr><td>Fall effect</td><td></td><td rowspan="3">Hazard Level</td><td rowspan="3"></td></tr>
<tr><td>Hazard distance</td><td></td></tr>
<tr><td>Safety protection</td><td></td></tr>
<tr><td>Noise</td><td></td><td rowspan="2">Environment Effect</td><td rowspan="2"></td></tr>
<tr><td>Illumination</td><td></td></tr>
</table>

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 2: Membership Functions for final stage

<table>
<tr><th>Functions</th><th>Variables</th><th>Membership Function</th></tr>
<tr><td rowspan="4">Input</td><td>Fatigue prediction</td><td>
</td></tr>
<tr><td>Hazard level</td><td>
</td></tr>
<tr><td>Environment effect</td><td>
</td></tr>
<tr><td>Safety risk</td><td>
</td></tr>
<tr><td>Output</td><td>Decision safety</td><td>
</td></tr>
</table>

Note: UC= Under control; NBr= Need break-time; NBh= Need Break-hour; TR= Total rest.

The inference process considers all the rule sets in accordance with knowledge-based from experience, database and expert opinions. In this study, the fuzzy rules were set by the multi- input single-output (MISO) controllers, consisted of five sets of fuzzy rules that indicated the stages in the developed system. For example, the fuzzy rule in syntax is shown below.

IF *antecedent* ***THEN*** *consequent*

IF *Heart rate is Low* ***AND*** *Body temperature is Low* ***AND*** *Record data is Low* ***THEN*** *The Performance is Low*

The best performance was reached when the heart rate and body temperature were in normal condition (medium category), but when the record data showed bad conditions, it should been warning to workers that conditions would getting worse during working hours and optimal performance have been achieved, so the recommendation was “break”. These conditions are represented in 27 fuzzy rules set (Table 3). The higher or lower heart rate during working hours also had an impact on fatigue. In construction activities, muscle fatigue occurred more easily, so when muscle activity generated into worse condition, it indicated that the worker was tired despite a normal heart rate. It would been worse if it was combined with bad conditions from external factors. 81 rules are identified from fatigue prediction in Table 4. It would be very dangerous with the highest level of hazard if the worker’s position was at maximum elevation and very close with the hazard area, even though safety protection was applied well in project site such as shown in Table 5 with 60 rules set. Table 6 shows 12 rules from the environment effect. The effect of noise in workers’ safety was higher than illumination, where illumination could still be adapted by workers to some extent, so that the environmental effect was minimal. Regarding the danger level, the combination of internal domination factors of workers and external conditions would caused conditions to get worse as shown in Table 7 with 108 rules.

Table 3: Fuzzy rules set for performance

No. Rules	Heart rate	Body temp.	Record data	Performance
1	Low	Low	Low	Low
2	Low	Low	Medium	Low
:				
27	High	High	High	Low

Table 4: Fuzzy rules set for fatigue prediction

No. Rules	Heart rate	Body temp.	Muscle act.	Working space temp.	Fatigue prediction
1	Low	Low	Low	Low	High
2	Low	Low	Low	Medium	High
:					
81	High	High	High	High	High

Table 5: Fuzzy rules set for hazard level

No. Rules	Fall effect	Hazard distance	Safety protection	Hazard level
1	Minor	Immediate	Absent	Low
2	Minor	Immediate	Not proper	Low
:				
60	Lethal	Far	Proper	Medium

Table 6: Fuzzy rules set for environment effect

No. Rules	Noise	Illumination	Environment effect
1	Low	Low	High
2	Low	Medium	Medium
:			
12	Very high	High	High

Table 7: Fuzzy rules set for safety decision

No. Rules	Fatigue level	Hazard level	Environment effect	Safety risk	Decision
1	Low	Low	Low	Low	Work
2	Low	Low	Low	Medium	Work
:					
108	High	Very high	High	High	Total rest

In this research, fuzzy inference system worked by using the Mamdani method (min-max method) which is started with **min** function for implication (rules aggregation) and then using **max** function for rule composition. Generally as stated in Equation 1 [1, 22]:

$$\mu(z) = \max_{k}\{\min(\mu_A(input_1), \mu_B(input_2))\} \quad (1)$$

With $\mu\ (z)$ is the solution value of fuzzy membership, and k is fuzzy rule number.

Defuzzification was the last phase in the analysis with the input derived from fuzzy rules composition. The final output was an exact number in fuzzy set domain within a certain range. Defuzzification by centroid method (central point (Z*) of fuzzy area as a crisp solution) is usually used in Mamdani as shown in Equation 2 [1,22].

$$Z^* = \frac{\sum \mu(z) z}{\sum \mu(z)} \quad (2)$$

With z is the fuzzy number of the linguistic term of Z and $\mu(z)$ is the value of fuzzy membership of z.

2.3.3 Model Test for Real-time Data

According to the identified variables, heart rate and muscle activity values were changing significantly during working hours, so it needed to be modeled based on the autoregressive principle, which represented a random process to predict the future according to the previous behavior. For this research, heart rate value was generated in accordance with the state dynamic equation model as stated in Equation 3 and Equation 4 [2, 20].

$$y_v(n) = y_v(n-1) + y_a(n-1)T \quad (3)$$

$$y_p(n) = y_p(n-1) + y_v(n-1)T + \frac{1}{2} y_a(n-1)T^2 \quad (4)$$

With $y_v(n) = \dot{y}_c(nT)$ be the true velocity at the n-th sampling instant, $\dot{y}_c(t)$ is instantaneous velocity. We had assumed that the acceleration $\ddot{y}_c(t)$ is constant over the sampling interval and that $y_a(n - 1)$ is the acceleration over $(n - 1)T \leq t \leq nT$.

Muscle fatigue activity could be defined by muscle force. At rest time, muscle force was maximal with 100%. This condition would decrease through working hours and the impact of workload until break-time reached. The muscle fatigue model was also defined as the asymptotic reduction of the peak of muscle fatigue torque to 50% over 100 seconds. Therefore, muscle fatigue model was developed in the context of the cycle-to-cycle control as exponential decrease of maximum muscle force (F_m) to 50% of the source value as a function of time alteration with decay constant as in Equation 5 [2].

$$F_{Max} = F_{\max 0} - \frac{F_{\max 0}}{2}\left(1 - e^{\frac{n-nf}{\alpha}}\right); n > nf \qquad (5)$$

With F_{max0} is the original value of maximum muscle force, n in this study refers to time with n_f is the time when muscles begin to fatigue, and α is the decay constant. In the case of muscle fatigue in the proximal muscles (shoulder flexors) and distal (fingers flexor) in repetitive movements, it was agreed that fatigue due to MVC strength was decreased by 18% and 24% [2, 5].

2.4 Application Prototype Development

All stages in the fuzzy process were outlined in a software application that was making it easier for users to be applied on-site through the interface provided. The compiled application consisted of several main menus to accommodate the needs of input and output data acquisition that would be used in the analysis. The main window showed some main menus (workers performance, monitoring, help, and exit), where each consisted of sub menus as shown in Figure 4 - 9.

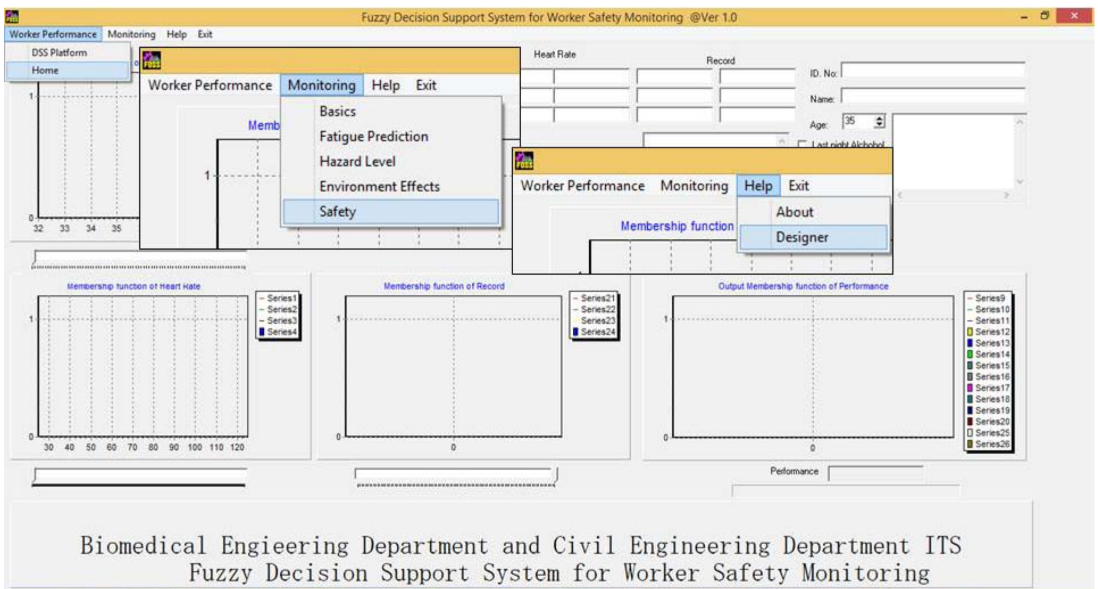


Figure 4: Main menu of application

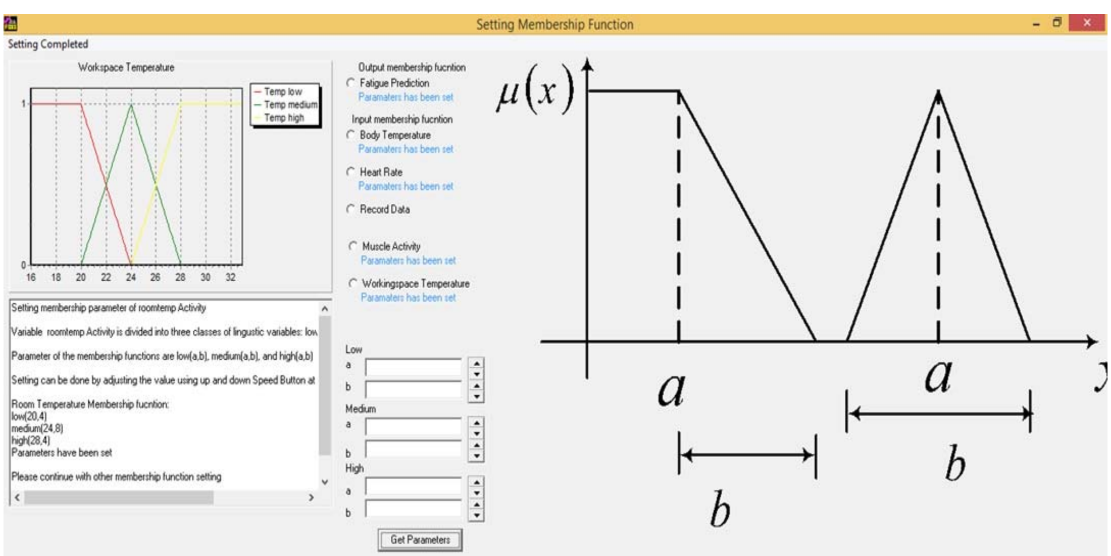


Figure 5: Menu of membership function setting

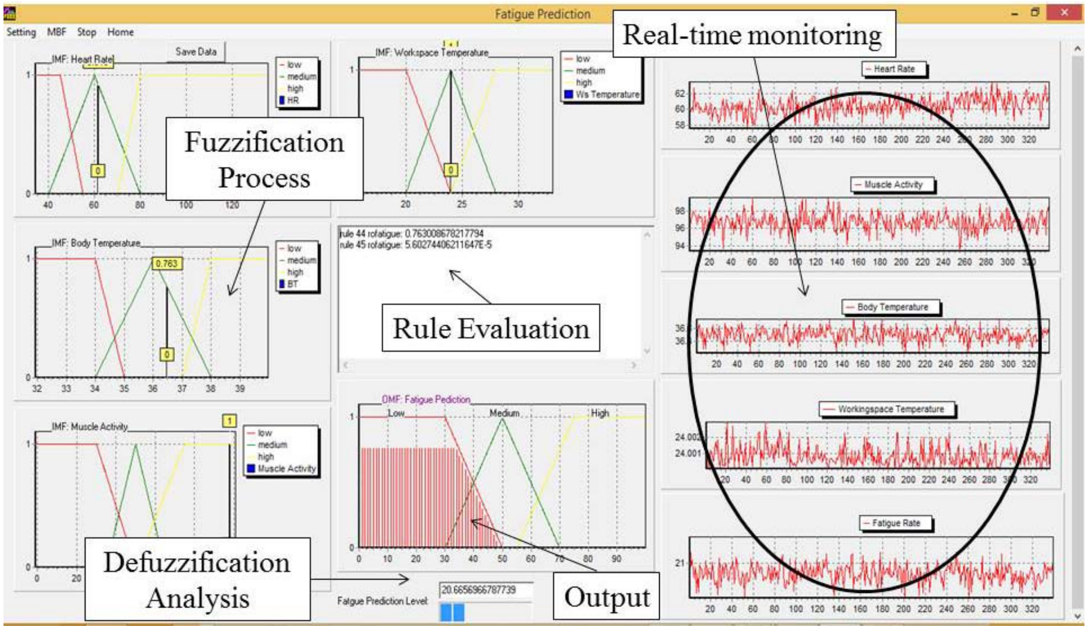


Figure 6: Menu of fatigue prediction analysis

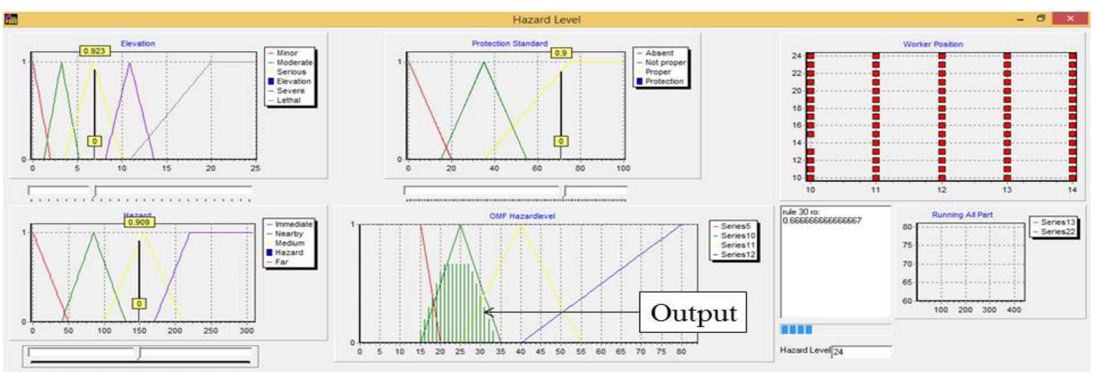


Figure 7: Menu of hazard level analysis

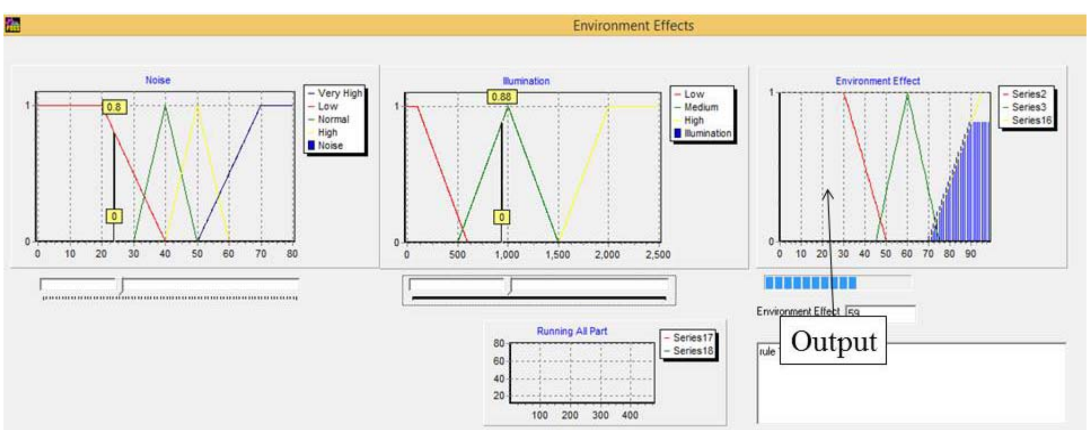


Figure 8: Menu of environment effect analysis

Journal of Theoretical and Applied Information Technology
31st December 2020. Vol.98. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

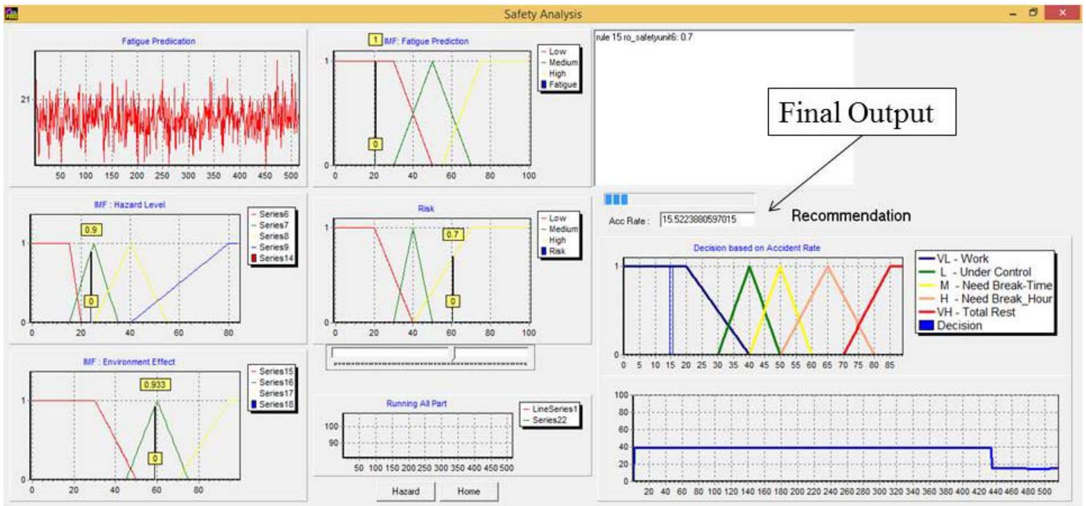


Figure 9: Safety decision analysis

Safety analysis was the final decision form for real-time monitoring systems, derived from previous subsystems such as prediction of fatigue, hazard levels, environmental effects and safety risks (Figure 9).

3. RESULTS AND DISCUSSION

3.1 Experimental Computation

Experimental computation on various conditions of worker safety on construction sites were conducted and solved to illustrate and verified the applicability of the developed application model.

For example, the DSS platform shows the worker's heart rate is 63 bpm (medium category) with the body temperature for 35.2ºC (medium). According to the record data, the worker's condition is medium with the value 40% (Figure 10). With these data, the model automatically shows the final performance in "high" category with a value of 87.006%. According to the rule sets, the fuzzy systems generated the data with the winning rule "IF the heart rate is medium AND the body temperature is medium AND the record data is medium THEN the performance is high". It means that the result of the developed system is the same with the design approach. Therefore, the DSS platform showed proper and running well according to the case.

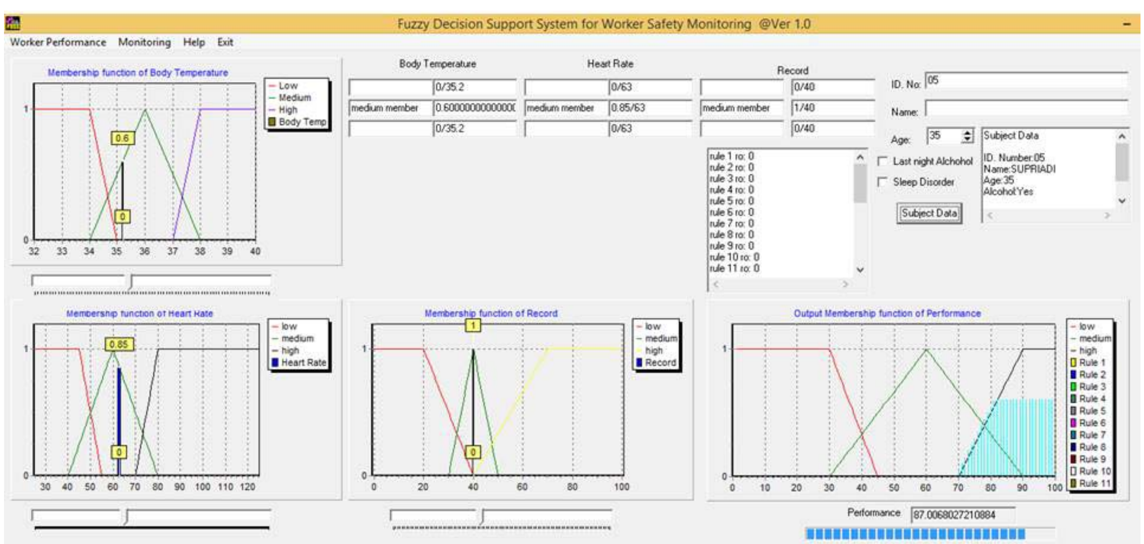


Figure 10: Performance for preparation work

Fuzzy approach in safety analysis as real-time monitoring on working hours was adopted from the DSS platform which has been verified in the previous discussion. The reliability of the safety analysis presented in Figure 9 shows the winning rule is number 15 with the degree of membership function is 0.7. According to the rules sets, "IF fatigue prediction is low AND hazard level is medium AND environment effect is medium AND risk is high THEN the decision is work". The final result in the developed system is 15.52 with the category is "work". Therefore the system denoted the appropriate logic functions and generated the input to final output properly.

3.2 Performance Evaluation

Based on the stages in fuzzy analysis, the system represented the appropriate output through experimental computations. The developed fuzzy decision system in the form of a program application was evaluated to ensure the overall system performance in accommodating various inputs from the safety conditions of construction workers at the project site. The consistency of the output membership function (OMF) of the DSS was evaluated with the designed rules, using the data model generated from real-time monitoring as system verification. In the rule evaluation with min-max operation (the Mamdani method), a number of rule sets generated to select "the winning rule", which was a non-zero number and confirmed with the result of the DSS execution in presenting "the winning rule". Many trials were executed with various input conditions so that the entire mapping rules could evaluate appropriately. If inconsistencies were found, the system would re-checked to search the principle of errors due to interpretation in the design that was not appropriate with the knowledge-based approach or caused by mistakes in the mapping process of the developed program. The evaluation progress was used as feedback for system improvement, thus a zero error rate is finally obtained (the accuracy of the fuzzy system leads to 100%).

Table 8: Performance evaluation for safety decision

Cases	The Execution from DSS						No. Win. Rule	Fuzzy Rules					
	F	HL	EE	R	D	OMF		F	HL	EE	R	D	Error
1	26.846	8.167	20.409	25	14.45								
	1.00	1.00	1.00	0.75		0.75	1	L	L	L	L	VL	0
2	21.527	8.167	20.409	25	15.44								
	1.00	1.00	1.00	0.75		0.75	1	L	L	L	L	VL	0
3	22.612	8.167	21.472	40	14.45								
	1.00	1.00	1.00	1.00		1.00	2	L	L	L	M	VL	0
4	23.527	8.167	20.958	66	14.45								
	1.00	1.00	1.00	0.867		0.867	3	L	L	L	H	VL	0
5	21.717	8.167	59	22	14.83								
	1.00	1.00	0.933	0.9		0.9	4	L	L	M	L	VL	0
6	26.35	8.167	59	40	14.7								
	1.00	1.00	0.93	1.00		0.93	5	L	L	M	M	VL	0
7	21.502	8.167	59	70	15.8								
	1.00	1.00	0.93	1.00		0.93	6	L	L	M	H	VL	0
8	21.737	8.167	87.712	14	15.61								
	1.00	1.00	0.708	1.00		0.708	7	L	L	H	L	VL	0
9	47.107	8.167	21.183	38	35.57								
	0.144	1.00	1.00	0.10		0.10	1	L	L	L	L	VL	
	0.144	1.00	1.00	0.80		0.144	2	L	L	L	M	VL	0
	0.855	1.00	1.00	0.10		0.10	37	M	L	L	L	L	
	0.855	1.00	1.00	0.80		0.80	38	M	L	L	M	L	
10	48.582	8.167	21.183	38	33.72								
	0.071	1.00	1.00	1.00		0.071	3	L	L	L	H	VL	0
	0.929	1.00	1.00	1.00		0.929	39	M	L	L	H	L	

Note: L= low; VL= very low; M = Medium; H = high.

Table 8 represents the system performance testing through a series of experimental data to evaluate the overall number of mapping rules. Each input condition provide the output of the DSS program execution and then these recommendations will be matched according to the designed rules based on the winning rule. For example in case 1, by inputting the predicted values for fatigue (F), hazard level (HL), environmental effects (EE), and risks (R), the DSS program will give a decision (D) as an output. According to the input data, the designed rules indicate that rule no. 1 is the winning rule, while the results from the DSS program execution show that the selected rule is

Journal of Theoretical and Applied Information Technology
31st December 2020. Vol.98. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

rule no. 1 with the degree of membership function (OMF) is 0,75 > 0. It states the consistency between the design and program execution is 100% (error rate is 0). Then the evaluation is continued for each rule from the whole rules that are designed.

3.3 Performance in Work Preparation

Workers' performance denotes the physiological condition of workers (heart rate, body temperature, medical histories) in morning preparation through the DSS platform menu. This analysis offers an opinion for safety officer or project manager in deciding worker's safety conditions in work preparation to prevent construction accidents. High-performance score means that the level of readiness is also higher for workers to complete their job during working hours.

Apart from medical histories, somatic factors also influence the readiness in work preparation such as age, lifestyle, and sleep disorders. The max value of heart rate is decreasing when a person is getting older. According to the expert opinions, it was stated that the effect of life style such as alcohol & smoke consumption (Ls), and sleep disorder (Sd) are increasing the heart rate until 10% (abnormal) as shown in Figure 11.

Based on previous studies, it was proven that smoking activity before work increases the heart rate value of 10 – 20 bpm (Kurnia Dewi, 2017). In abnormal conditions affected by somatic and record data, the performance was running lower than normal condition as summarized in Figure 12.

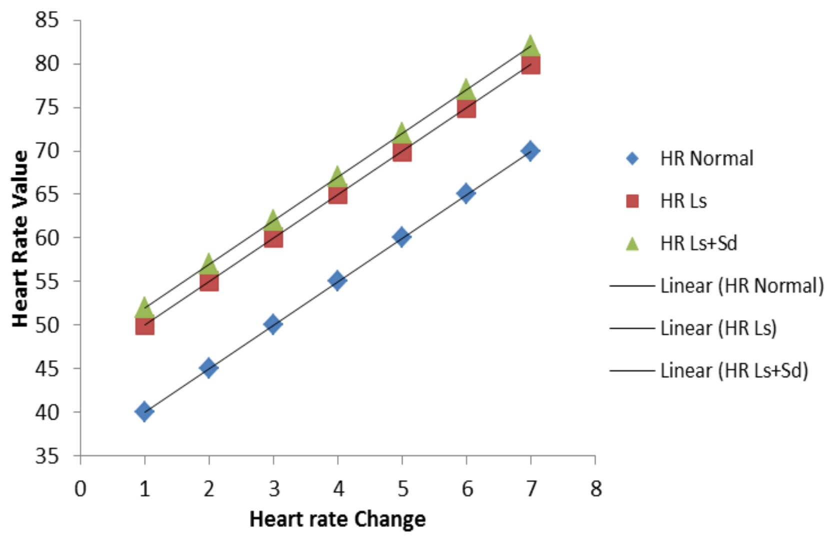


Figure 11: Heart rate trend based on record data

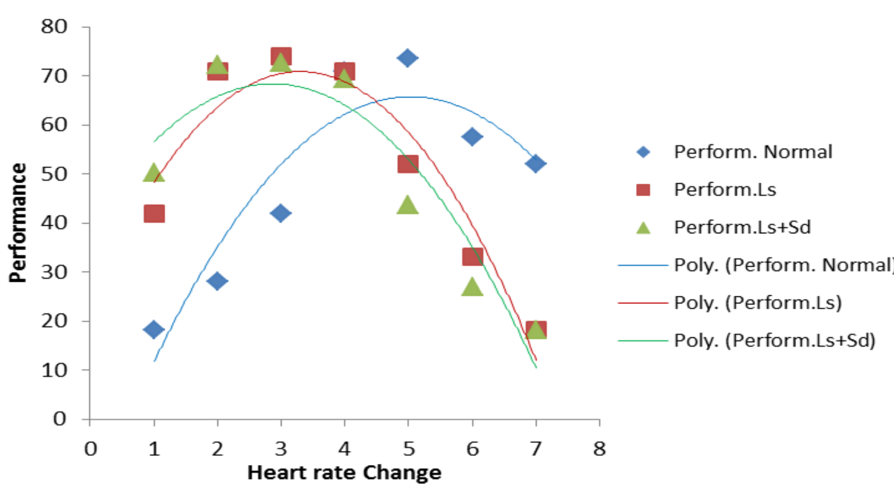


Figure 12: Performance of workers in normal and abnormal conditions

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3.4 Real-time Monitoring on Working Hours

The decision on worker's readiness will determine the measurement of real-time monitoring on working hours. Real-time monitoring is influenced by external factors such as workload, therefore HR and MA as significant variables that changed with the time function were developed by following equations 2 and 3. Heart rate value increased based on the exertion of workload and muscle activity would decrease according to the deficiency of muscle strength in workload resistance. The behaviours of heart rate and muscle activity are shown in Figure 13.

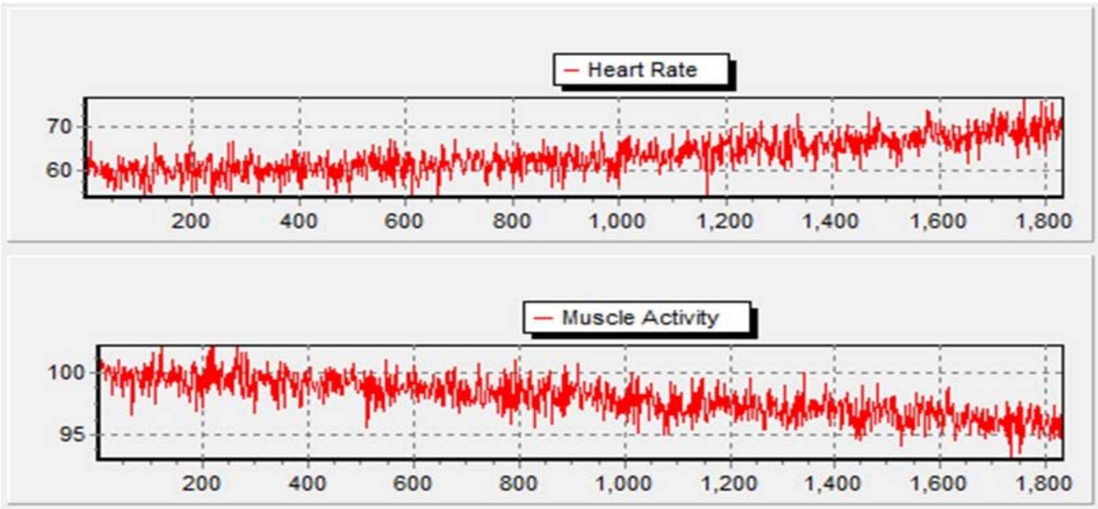


Figure 13: Heart rate and muscle activity behaviours in real-time monitoring

Real-time monitoring system on working hours were measured based on safety risk from previous project experience, fatigue condition as internal factors, the level of hazard, and environment condition of the project site as external conditions. According to these measurements (subsystems), the suggested decision was the final goal. In this study, fatigue was analyzed in real-time based on time function, whereas for hazard level and environment effect, were conducted with a discrete approach because the changes tend to be stagnant as illustrated in Figure 9. Various conditions could be happened during working hours. This behavior would recommend different decisions for workers' safety. The system simulates the condition of workers in real-time monitoring (Table 9).

Table 9: Simulation condition of workers in real-time monitoring

No.	HR (bpm)	BT (^{0}C)	MA (%)	WST (^{0}C)	FE (m)	HD (m)	SP (%)	Noise (dB)	Illum. (Lux)	Risk (%)	Accident Rate	Decision
1.	61	36.1	90.43	24	12	2.1	42	45	839	41	21.88	Work
2.	60	36.5	80.00	26	6	2.4	10	10	1250	35	23.00	Work
3.	59	34.1	90.77	24	10	1.5	67	39	1478	60	27.01	Work
4.	58	38.6	89.44	24	11	2.4	37	45	967	49	33.69	UC
5.	61	34.2	88.83	24	10	1.6	67	39	1478	60	35.23	UC
6.	60	36.5	79.00	26	20	0.1	23	40	400	48	39.00	NBr
7.	80	36.5	27.00	26	4	2.4	75	15	1250	20	64.00	NBh
8.	41	36.5	86.69	24	10	1.0	78	33	839	67	81.06	TR
9.	38	34.1	88.85	24	20	1.0	79	19	100	83	81.15	TR
10.	80	36.5	27.00	26	20	0.1	25	25	1050	50	85.00	TR

Note: UC= Under control; NBr= Need break-time; NBh= Need Break-hour; TR= Total rest.

Table 9 shows the first condition, if all the factors are in almost normal conditions, then the accident rate is low and the recommendation for decisions is “still work”. The second condition is when the internal factors are good while the external factors are danger, with the risky level of safety, then the result indicates low rate, so the recommendation is “still work” but in “under control” if the condition is getting worse. In the next phase, if the internal conditions are normal, and the external conditions are dropped and the safety risk is medium, so the accident rate is getting worse and the recommendation for the worker is “need break-time”, but if these conditions are combined with abnormal internal factors, it is recommended “need break-hours” to re-charge the condition. The last subject, if the internal and external factors are in bad conditions, then the accident rate is high and “total rest” for the worker as the recommendation.

3.5 Integrated Safety Monitoring System

As an integrated system, there is a relationship between measurement in work preparation and during working hours as a comprehensive effort to prevent construction worker accidents. Other simulations were conducted to show this relationship (Table 9). From Table 8, several conditions are executed from the preparation stage through the DSS platform and then proceed with fatigue prediction as the first result of real-time monitoring.

Table 10: Relationship between performance and real-time monitoring

No.	HR (bpm)	BT (^{0}C)	RD (%)	MA (%)	WST (^{0}C)	Performance (%)	Fatigue Prediction (%)	Recommendation
1.	40	34.0	90	90.72	24	18.252	80.535	Rest
2.	38	34.1	85	88.85	24	19.209	80.427	Rest
3.	41	33.9	70	89.32	24	21.229	79.997	Rest
4.	80	36.2	94	90.01	24	18.572	49.000	Under Control
5.	59	34.1	95	90.08	24	60.225	47.482	Under Control
6.	79	36.7	88	88.99	24	22.990	46.541	Under Control
7.	58	34.2	90	88.99	24	61.392	44.233	Under Control
8.	58	36.1	87	89.44	24	88.124	20.008	Work
9.	61	36.1	90	90.43	24	88.825	19.930	Work
10.	60	36.0	85	88.61	24	88.439	19.769	Work

Table 10 shows that poor physiological conditions in the morning causes low performance and not ready to work. The prediction of fatigue is also high when starting work and can get worse during working hours. Performance and fatigue prediction based decisions recommend workers "rest." The decision of safety also indicates a high accident rate for workers so they are not allowed to work. Another case shows that normal physiological conditions will lead to good performance and ready to work. The prediction of fatigue also indicates normal conditions but should be aware that the physiological conditions worsen during work. The "work" recommendation is given based on performance and predictions of fatigue, while the decision of safety shows a low incident rate but must work under supervision. If the physiological measurements in the morning show normal conditions, then the performance is maximal and no indication of fatigue is detected, so it is safe to work.

3.6 Discussion

The developed system has been realized based on internal and external conditions in accordance with knowledge-based form experience, database and expertise to support the recommendation for decision making in worker’s safety in work preparation and on working hours.
The fuzzy approach is used in realizing the decision support system since the accuracy of this method to analyze qualitative issues such as safety assessment The fuzzification as the first step in fuzzy systems are changed the input data into their membership functions to generate fuzzy inference system with fuzzy rules are set by MISO controller, worked by the Mamdani method (min-max method) to find the decisions as the final goal of safety monitoring for

construction workers through defuzzification mechanism.

The performance of system has been validated with a series of real-time monitoring data through the consistency of each designed fuzzy rule with the results from the developed DSS program. The comparison between DSS execution and the designed rules stated an error value of 0. It means that the system performance showed 100% of consistency. It indicates that knowledge-based approach in the design process could be realized in the form of fuzzy decision support system. With a fuzzy system-based analysis approach, it could be ensured that decision making would be easier. A knowledge-based analytical approach that accommodates the logic of human thinking such as FDSS was needed for decision-makers related to the safety of construction workers at the project site and developed in the form of a software application to facilitate operation.

The DSS platform and safety analysis showed that the decision support was reliable for the system analysis according to the verification process. The DSS platform was proper to illustrate the readiness in work preparation while the safety analysis has delivered a recommendation for the decision of accident prevention according to the internal and external conditions.

Several different conditions have been generated in the developed system to describe the real conditions. Historical data and physiological of workers affect the performance in work preparation and also influenced by somatic factors, lifestyle, and sleep disorder. Maintaining physiological factors in normal conditions was very important to determine "good performance" as the readiness to work. If the "work" decision has been recommended, then proceed with real-time monitoring during working hours. A good performance condition that was supported by a good muscle activity level led "no fatigue" condition of workers to start the activities. All of the variables, heart rate and muscle were generated based on time function, modeled with autoregressive equation in real-time monitoring. The final decision was recommended from the safety analysis.

The realized system needed some improvement for further research to find the real condition in construction project with other variables and the effect of its behaviour. The integration between sensor networks and this developed model system is needed to achieve our final goal in modern safety management system in construction.

4. CONCLUSION

A real-time monitoring for construction workers safety on working hours which was developed according to the integration of worker conditions as internal factors and external factors from environmental project was proposed. The proposed system consisted of fatigue prediction mechanism, analysis of hazard level and environmental effects, and safety risk assessment from management, in a comprehensive analysis for decision-making. The development of monitoring system has been realized in the form of fuzzy decision support system (FDSS). Fuzzy logic works with human reasoning-based approached which was proper to analyze the problem with qualitative assessment such as safety analysis and according to the tested model, the fuzzy process was more appropriate for decision-making analysis. FDSS was designed as a real-time monitoring based on complete aspects, both from the condition of workers and construction sites, thus making safety decisions were easier, more accurate, always updated and better in preventing accidents. The experimental computation with the simulation process is shown good performance in describing the safety condition of workers. System validation shows that the FDSS application is capable in assisting the decision recommendations. The final result was useful for the recommendation for accident prevention, especially for construction workers.

5. ACKNOWLEDGEMENT

This research was supported by Beasiswa Pendidikan Pascasarjana Dalam Negeri (BPPDN) grant fiscal year 2015 (No. 906.15/E4.4/2015) and Penelitian Disertasi Doktor (PDD) Kemenristek Dikti grant fiscal year 2019 (No. 729/PKS/ITS/2019).

REFRENCES:

[1] Arifin, A., *A Computer Simulation Study on The Cycle-to-Cycle Method of Hemiplegic Gait Induced by Functional Electrical Stimulation*, Sendai: Department of Electrical Engineering, Tohuku Uviversity, 2005.

[2] Arifin, A., Watanabe, T., & Hoshimiya, N., Design of Fuzzy Controller of the Cycle-to-Cycle Control for Swing Phase of Hemiplegic Gait Induced by FES, *IEICE Transactions on*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Information and Systems, 2006, pp.1525 - 1533.

[3] Arifin, A., Watanabe, T., & Masuko, T., Application of Knowledge Engineering and Fuzzy System in Realizing Cycle-to-Cycle Control Method for Swing Phase of FES-induced Gait. *3rd Internastional Symposium on Medical, Bio-and Nano-Electronics,* Sendai, Japan: Education Program for Biomedical and Nano-Electronic, Tohoku University, 2008, pp. 43 - 51.

[4] Cheng, M. Y., & Tran, D. H. (2015). Opposition Based Multiple Objective Differential Evolution (OMODE) for Optimizing Work Shift Schedules. *Automation in Construction 55*, 1-14.

[5] Cowley, J. C., & Gates, D. H., Proximal and Distal Muscle Fatigue Differentially Affect Movement Coordination, *PLoS One*, 2017, pp.1-17.

[6] Dong, H., Ugalde, I., Figueroa, N., & Saddik, A. E. (2014). Towards Whole Body Fatigue Assessment of Human Movement: A fatigue Tracking System Based on Combined sEMG and Accelerometer Signals. *Sensors 14*, 2052-2070.

[7] Fang, Y. C., & Dzeng, R. J., A Smartphone Based Detection of Fall portents for Construction Workers, *Creative Construction Conference 2014, CC2014,* Procedia Engineering, 2014, pp. 147-156.

[8] Goh, Y. M., & Sa'adon, N. F., Cognitive Factors Influencing Safety Behavior at Height: A Multimethod Exploratory Study, *Journal Construction Engineering Management*, 141 (16), 2015.

[9] Gunduz, M., Birgonul, T., & Ozdemis, M., Fuzzy Structural Equation Model To Assess Construction Saite Safety Performnace, *Journal of Construction Engineering and Management*, 2017.

[10] Hallowell, M., & Gambatese, J., A Formal Model for Construction Safety Risk Management, *The Construction and Building Research Conference of The Royal Institution of Chartered Surveyors,* Georgia Tech, Atlanta: RICS and Georgia Tech, 2007.

[11] Haumaru, M., & Aotearoa, Fatigue in Construction. *Safety, Health and Welfare on Construction Site*, 2014.

[12] Isaac, S., & Edrei, T., A Statistik Model for Dynamic Safety Risk Control on Construction Sites, *Automation in Construction 63*, 2016, pp.66-78.

[13] Javadi, M., Saeedi, G., & Shahriar, K., Fuzzy Bayesian Network Model For Roof Fall Risk Analysis In Underground Coal Miners, *Journal of Applied Sciences*, 2017, pp.103-115.

[14] Jiang, Z., Fang, D., & Zhang, M., Understanding The Causation of Construction Workers' Unsafe Behaviors Based on System Dynamics Modeling, *Journal Management Enginnering 31 (6)*, 2015.

[15] Khamesi, H., Torabi, S. R., Nasirabad, H. M., & Ghadiri, Z. (2015). Improving the Performance of Intelligent Back Analysis for Tunneling Using Optimized Fuzzy System: Case Study of the Karaj Subway Line 2 in Iran. *Journal of Computing in Civil Engineering, 29 (6)*, 1-12.

[16] Kurnia Dewi, S., *Relationship Between The Level of Physical Fitness and The Frequency of Heart Rate in Nursing Students Last Semester at Muhammadiyah University Yogyakarta*, 2017, Retrieved October 31, 2019, from http://repository.umy.ac.id/handle/123456789/15284.

[17] Li, H., Chan, G., Huang, T., Skitmore, M., Tao, T. Y., Luo, E., et al., Chrip Spread Spectrum Based Real Time Location System for Construction Safety Management: A Case Study, *Automation in Construction 55*, 2015, pp.58-65.

[18] Limbong, N. Y., Josephus, J., & Kawatu, P. A., *Description of Work fatigue Measurement for Workers with Objective and Subjective Methods at PT. Sastramas Estetika Megamas Kota Manado*, 2015, Retrieved February 17, 2016, from https://docplayer.info/69314945-Fakultas-kesehatan-masyarakat-universitas-sam-ratulangi-manado.html.

[19] Lin, Y. H., Ho, S. C., & Lai, C. Y. (2015). Physiological Workload and Musculoskeletal Fatigue Among Construction Workers Involving Squatting/ Kneeling Task in Taiwan. *Proceedings 19th Congress of the IEA*, (pp. 1-6). Melbourne.

[20] Manolakis, D. G., Ingle, V. K., & Kogon, S. M., *Statistical and Adaptive Signal Processing: Spectral Estimation, Signal Modeling, Adaptive Filtering, and Array Processing,* Boston: McGraw-Hill, 2000.

[21] Patel, D., & Jha, K., Neural Network Model for Prediction of Safe Work Behavior in Construction Projects, *Journal Construction Engineering Management 14 (1)*, 2015.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[22] Ross, T. J., *Fuzzy Logic with Engineering Applications, second edition,* Chichester, Wesy Sussex: John Wiley & Sons, Ltd, 2004.

[23] Russell, H., Maitre, B., & Dorothy, W., *Trends and Patterns in Occupational Health and Safety in Ireland,* Dublin: The Economic and Social Research Institute, 2015.

[24] Sooksil, N., & Benjaoran, V., Validation of Construction Safety Equilibrium Model on High Rise Building construction Project in Thailand. *Procs 30th Annual ARCOM Conference,* Portsmouth, UK: Association of Research in Construction Management, 2014, pp. 371-379.

[25] Teizer, J., & Cheng, T., Proximity Hazard Indicator for Workers on Foot Near Miss Interactions With Construction and Geo Referenced Hazard Areas, *Automation in Construction 60*, 2015, pp.58-73.

[26] Wang, D., Dai, F., & Ning, X. (2015). Risk Assessment of Work Related Musculoskeletal Disorders in Construction: State of the Art Review. *Journal of Construction Engineering and Management.*

[27] Winanda, L. A., Adi, T. W., & Anwar, N., Model Prediksi Kelelahan Pekerja Konstruksi Di Lokasi Proyek, *Jurnal Ilmiah Teknik Sipil Vol. 21 No. 2 July*, 2017, pp.99-107.

[28] Winanda, L. A., Arifin, A., Arrofiqi, F., Adi, T. W., & Anwar, N., A Design Concept of Fuzzy Decision Support System for Construction Workers Safety Monitoring. *International Conference on Sustainable Civil Engineering Structures and Construction Materials (SCESCM 2018),* Yogyakarta: MATEC Web of Conferences Vol. 258 (2019), 2019, pp. 1-101-10.

[29] Wirahadikusumah, R. D. (2014). *Tantangan Masalah Keselamatan dan Kesehatan Kerja Pada Proyek Konstruksi Di Indonesia.* Retrieved 2016, from http://beta.lecture.ub.ac.id/files/2014/01/makalah-reini-d-wirahadikusumah.pdf

[30] Wong, D. P., Chung, J. W., & Chan, A. P., Comparing the Physiological and Perceptual Responses of Construction Workers (Bar Benders and Bar Fixers) in A Hot Environment, *Applied Ergonomics 45*, 2014, pp.1705-1711.

[31] Zhang, M., Sparer, E. H., Murphy, L. A., Dennerlein, J. T., Fang, D., Katz, J. N., et al., Development and Validation of A Fatigue Assessment Scale for U.S Construction Workers. *Am J Ind Med February 58 (2)*, 2015, pp.220-228.