p–ISSN: 2723 - 6609 e-ISSN: 2745-5254
Vol. 5, No. 9 September 2024 http://jist.publikasiindonesia.id/

Factors Affecting Control Room Operator Situation Awareness and ITS Fuzzy Logic Model

Asep Karmana[1]*, Fergyanto E. Gunawan[2], Muhammad Asrol[3]
Universitas Bina Nusantara, Indonesia
Email: karmana64325@gmail.com[1*], fgunawan@binus.edu[2], muhammad.asrol@binus.edu[3]

*Correspondence

ABSTRACT

Keywords: alarm management, cognitive behavior, control room operator (CRO), fatigue, heart rate.

The rapid development of computer-human interface in process industries control systems challenged control room operator (CRO) to maintain their situation awareness (SA) at a high alert level. The paper aims to present physiological factors affecting the work performance of CRO wellness status during their duty to measure their SA level. PERCLOS number of eye-opening recognition and heart rate profile used as physiological variable to measure fatigue effect. Alarm management records and response time spent in controlling process changes behavior are used as cognitive behavior variables representing competency performance. Fuzzy logic methods were selected to correlate the input variables to the SA level as output variables that will be useful to communicate the CRO situation awareness status into the computer-human interface as an alert system for the CRO themselves or further to their supervisor for any intervention required. Results of the observation and analysis show a significant correlation between the observed physiological of the CRO and the cognitive behavior of the CRO at different stress level working conditions. The findings support the development of a wellness alert system in process industries' control systems by enhancing the SA level of CRO effectively.

Introduction

The role of the control room operator panel operator or board operator in the process industries is becoming very critical with the continuous and emerging development of industry automation in particular to control the system. (Rozo et al., 2016). New inventions and innovations in human-machine interface (HMI) and network system design capability are intensively growing along with the amazing delivery of sophisticated technologies for information and telecommunication (IT), computer science, and engineering, which is collaboratively deployed in the process control system and its application in the industrial automation. Those inventions and innovations are not limited to hardware and software part but also touch on the human factors aspect and usability (Wibowo, 2023).

Although the development of machines, hardware, and software is considered a very advanced stage, incidents and accidents in the process industries such as oil and gas, petrochemicals, chemicals, and nuclear facilities are still observed as catastrophic with large consequences in cost and fatality. (Skarphéðinsson & Mohan, 2017). Studies conducted by Willis Engineering on the Willis Energy Loss Database (WELD) in the last 30 years, in addition to the loss of life, the financial losses for the event with a total loss value of over USD 50 million cumulatively reached more than USD 25 billion from only property damage and business interruption. (Rozo et al., 2016).

Human error was the main cause of the most tragic recent incident in the large processes industrial complex of the oil & Gas, nuclear, and petrochemicals industries. (Mikelsten, 2019). Marsh JLT Specialty reported the 100 largest losses in the Hydrocarbon Industry incident from 1974 -2019 where the incident caused a loss value higher than US$ 500 Million indicated in the below table. (Panel et al., 2014).

Table 1
Hydrocarbon Industry Value Loss from Incidents from 1974 – 2019

Past Period		Recent Period (2018-2019)	
Loss Value * (US$-Million)	Location	Loss Value * (US$-Million)	Location
2,088	Piper Alpha, North Sea, UK	800	Jiangsu, China
1,615	Pasadena, Texas, USA	750	Philadelphia, USA
957	Gulf of Mexico, USA	650	Wisconsin, USA
811	Campos Basin, Brasil	600	Limbe, Cameroon
737	Nevada, US		
708	Louisiana, USA		

*Calculated on basis of December 31, 2019

The specific case as an example of human errors made by the control room operator is the incident of the fire and explosion that happened at BP Texas City Refinery (Pasadena) on March 23, 2005, at 01:20 p.m. The incident occurred during the plant's commissioning after plant turn-around maintenance, where the alarm system failed to notify the control room operator that an unsafe and abnormal situation existed within the tower, and the blowdown drum – was overfilled with the flammable liquid. As reported on the final investigation report issued by the US Chemical Safety and Hazard Investigation Board (CSB), the incident caused 15 fatalities, 180 injuries, and financial losses exceeding USD 1.5 billion. The release of flammables led to an explosion and fire. All the fatalities occurred in or near office trailers located close to the blowdown drum. A shelter-in-place order was issued that required 43,000 people to remain indoors. Houses were damaged as far away as three-quarters of a mile from the refinery (US CSB, 2005) (Campbell, 2021).

Despite the other root causes within the above BP Texas City Refinery case, the control room operator and his supervisor have been pointed out as the major contributing factor to the incident. The fact, over three hours of flammable liquid filling a distillation tower without any further doubt or action on the process going on, indicates a degradation in his situation awareness as a result of mental workload, fatigue, boredom, distraction, and/or other human factors after long heavy work during the turn-around maintenance execution. (Kurnia, 2016).

Human error is considered a normal function of humans; it is inevitable but may be preventable. Although the recent development in industrial Advance Process Control (APC) systems has been successfully demonstrated and applied in some parts of process plants, eliminating the human part from the process control of integrated plants is practically almost impossible. From the thirty years of author experience in the process industries, in reality, even APC operated unit will need an intervention from a control room operator in many situations, at least for monitoring and adjusting set point. However, the control room operator is a normal human being like all others makes mistakes and has lapses in attention. Therefore, all efforts involving all the stakeholders should be made, and management systems and tools to help reduce the error rate to the minimum possible level. (Tanjung & Nasution, 2005).

Safety in process plants is at the top of the list of issues that are yet to be resolved fully. Recent accidents and their impact on the economy, environment, and human lives have raised this issue once again. There are many causes for such accidents and many reports have been published to explain why such accidents happen. (Sakti & Setiyawan, 2024). All of these have a common point of view, which is related to the environment of the process control room. Human operators are at the heart of the control room as responsible parties for proper monitoring and controlling of plant operations through observing information from resources present inside the control room. Massive information is faced all the time such as sudden bombardment with a lot of alarms under abnormal situations can make operators paralyzed and lead to overwork, stress, and fatigue. (Winarsunu, 2008).

A variety of methods are available in literature such as root cause analysis, removal of alarm chattering, procedure and job aids, etc. to help control room operators and make the control room much more friendly to control room operators. Nevertheless, their implementation and usefulness in process plants have yet to see a significant level of success. The usefulness of these methods depends on the extent to which these methods can help operators. As an example, from the fellows working in the control room, the information overflow and alarm flooding often confuse the operator, and it impacts missing attention to critical alarms that may cause accidents to happen. (Aeberhard-Hodges, 2019).

Instrumentation and control system designs have been developed based on the latest advanced technology to reduce delay time and make the instrumentation reliable with faster response time. In addition, the fascinating computation technique complemented by software and computer technology made automation systems possible to resolve any complex and integrated processing requirements. However, this supercomputer and control generation does not mean reducing the workload of the control room operator but adversely demands the control room operator to enhance their capability to operate and be familiar with many elements to be memorizing. This mentally loaded the operator with additional cognitive tasks and responsibilities.

Hence, a control room operator is a normal human who lives with a certain limited capacity mentally and physically. They are usually working between 8-12 hours in a shift work schedule. As mentioned by the International Labor Organization (Hadwiger, 2018), the normal maximum working hours should not exceed 8 hours but it can be extended to a certain agreed consensus between the parties involved. Thus, the situation awareness level is unlikely to be the same for the entire duration exceeding 8 hours per day. A preliminary survey indicated that more than 80% of respondents signaled the need for physical and mental fitness observation throughout their duty time, and to activate the supervisor roles more vigilant by intervening in the mental/physical degraded on-duty control room operator and improve their level of perception, comprehension, and projection to the standard criteria.

Most of the efforts in supporting high-level situation awareness concentrating on physical attributes, wellness, and mindfulness of the control room operator were almost dismissed. Wellness and mindfulness are the keys to human factors to perform and be able to maintain their healthiness of cognitive action for maintaining situation awareness effectively. Therefore, the study on the wellness of control room operators will be able to support the other human factors and concerns related to system awareness.

Method

The objectives of the design research are to assess the variables and parameters affecting control room operator physiological and cognitive behavior that will provide input to the advanced human behavior monitoring of control room operators possibly embedded in human-machine interface (HMI). Physiological and cognitive performance of control room operation while carrying out his duties will be measured as an inherent parameter and utilized as input into a situation awareness model that will rate the control room operator's wellness and mindfulness.

Tremendous workload and expertise requirements to interface with control room operation elements can be structurally and strategically managed to deliver the proper steps of actions and maintain their fitness to operate under controllable wellness.

Looking into the facts that none of the provisions to the control room operator wellness established in the process industry practice, therefore, it is very challenging to study and deliver the prototype design for the Visual Observer and Wellness Alert as an integrated part of human factors focus of the control room development. The study is aims and willing to explore the following objectives:

1) Utilizing simple commonly use devices to capture the physiological and cognitive behavior and performance of control room operators, that work to evaluate the wellness and behavior changes while control room operators carry out their duty.
2) To assess and analyze that physiological parameters/variable and their cognitive performance have having good correlation and are suitable to be used as the basis for developing and designing wellness alert/control devices that can improve control room operator situation awareness level.
3) To propose a fuzzy logic-based model to interface the captured information from physiological parameters/variable and their cognitive performance into the design of the Wellness Alert system, in terms of situation awareness status, as output signal

received by the supervisory workstation and provide the supervisor on the possible cognitive-behavioral and physical coaching intervention.

Overall, the target study is aimed to cover all the below workflow described in Fig.2, however, the discussion in this paper will only focus on the third column of the chart looking into the physiological and performance Factor Assessment.

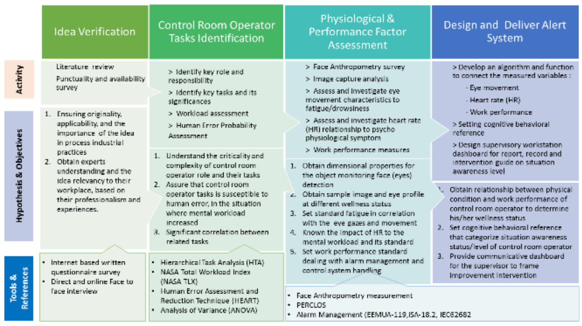

Figure 3. The Overall Research Workflow

The ultimate intention of the study is to design a visual Observer and Wellness Alert that will be embedded into human human-machine interface connected to a supervisory control desktop for peer or high-level intervention as described in Fig. 4 and Fig. 5 below.

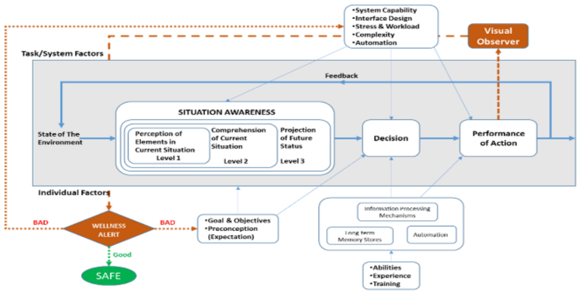

Figure 4. Conceptual Design of Visual Observation and Wellness Alert

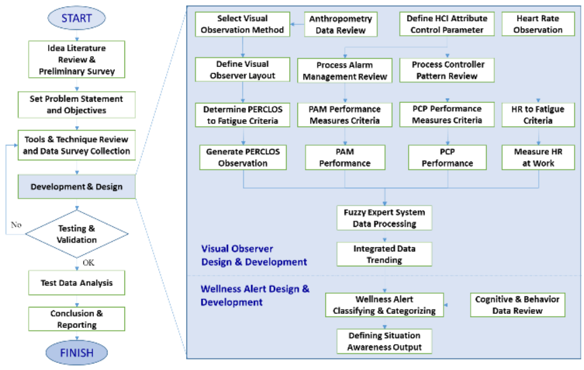

Figure 5. Research/Study Framework

Data Correlation Validation

The collected physiological observation data of PERCLOSE and Heart Rate (HR), cognitive behavior observation data of the Response Time (RT) taken by the operator to resolve any process condition abnormality, and cognitive performance achieved through counting the number of Alarms appear during the observation period, modeled using multi-variable linear regression method with #Alarm [Y] as dependent variable, and PERCLOSE [P], Heart Rate (HR), and the Response Time (RT) as independent variables following the below scheme.

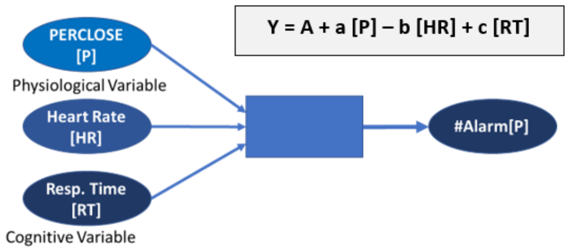

Figure 8. Inter-variable Correlation Test and Validation

The regression analysis should be sufficient to confirm if between variables have a significant correlation and be able to see each behavior, character, and wellness trend while carrying out their tasks and duties.

Results and Discussion

The research study involves 3 professional control room operators (CRO) currently working in a petrochemical plant with a different range of service years (all above 10 years) and different field experience in oil & gas and petrochemical company, specifically expert in plant operation control mainly called as a board operator. Observation was taken during 2 working days of 12-hour day shift and a 12-hour night shift. It was fortunate that during the observation period, there was a chance of plant start-up, emergency shutdown, and process anomaly, where a set of normal operation conditions and upset operation conditions can be collected.

PERCLOS data was collected using a camera recording installed in front of the CRO DCS console furnished by face recognition of eye blinking and %--closure, while Heart Rate was recorded using a smart watch worn by CRO for the full observation period. From the live records, data was extracted manually through a sanitizing process to eliminate unqualified data such as the data capture while the CRO was not performing the tasks. PERCLOS data extraction uses a fraction of the pictures generated from a film. Heart Rate data extracted from the trend on the smartwatch HR record. For Response Time, data is extracted from the trend of some of the bad actor controllers in the DCS memory trend, and #Alarm was picked up from the Alarm Management system installed in DCS.

Table 7. Data Regression Summary

Object	A Intercept	Multiple Regression Coefficient	P-Value

		a [P]	**b** [HR]	**c** [RT]	[P]	**[HR]**	**[RT]**
CRO – 1 (Normal)	+173.7	+0.96	-2.01	+3.72	1.64E-05	0.0117	0.2488
CRO – 1 (Upset)	-2.06	+0.34	-0.03	+11.41	0.0141	0.9095	2.63E-06
CRO – 2 (Normal)	+118.5	+0.77	-1.53	+7.47	0.0082	0.1311	0.05
CRO – 2 (Upset)	+23.68	+0.45	-0.33	+5.14	1.40E-03	0.0259	0.0026
CRO – 3 (Normal)	+111.15	+1.07	-1.58	+7.01	4.33E-05	0.0259	0.0026
CRO – 3 (Upset)	+56.28	+0.25	-0.67	+4.91	1.36E-02	0.0046	0.0086
Aggregate (Normal)	-21.41	+1.09	-0.02	+9.88	2.42E-13	0.8967	1.27E-09
Aggregate (Upset)	-9.07	+0.48	+0.02	+8.03	2.70E-10	0.7721	5.59E-12
Aggregate (Overall)	-23.35	+0.76	+0.097	+11.87	1.07E-26	0.1953	6.62E-32

After segregating the extracted data, 44 points of 10-minute average data were collected from each mode of operation per each CRO. The total aggregate data is 264. The quality of data is considered very good with clear trending of the raw data itself.

Physiological and Cognitive Factors Correlation

Referring to Table 7 above, the result of multi-regression indicated a very well-consistent and significant correlation between the independent variables (PERCLOS, Heat Rate, and Response Time) with the dependent variable (#Alarm). This is very clear from the statistical p-value of the 9 sets of linear regression to each independent variable with p-value <0.05. CRO-1 Normal operation data has having slight anomaly on Response Time data due to an unplanned operation testing requirement on the analyzer with the vendor The DCS trend record has been suspended for testing purposes. However, in general, the set of data is satisfactorily represented and aligned with the hypothesis of the research.

As general findings, PERCLOS and Response Time (RT) hurt the CRO performance as the more %-Closure increase and longer Response Time to bring operating control parameter to the control point giving more #Alarm that may reduce the situation awareness of the CRO. Meanwhile, Heart Rate variable changes seem to be insignificant to impact the CRO performance and very situational. This is understandable due to the comfortable place and professionality of the sample CRO for the study that having long experience and maturity in knowledge and handling the process changes. Therefore, the variation in heart rate is much less. The findings are also supported by the P-value from ANOVA indicates less than 0.05 for the three independent variables (PERCLOS, Heart Rate, and Response Time), which means the correlation between the variables is significant.

In specific, it is also found that the model can predict the situation awareness behavior level of individual CROs in response to the operating condition and status of the plant. The three object CRO in the study demonstrated different characteristics of performance concerning the tree variable measures in different plant statuses (Normal and Upset condition). Object CRO-1 shows an opposite behavior compared to Object CRO-2 and CRO-3 which is indicated by the coefficient value of each variable for normal and upset situations. Based on their working experiences CRO-1 is the least among them.

Looking into the aggregate model, it was validated that PERCLOS and Response Time give a very strong correlation to the performance measures, and the Heart Rate is very situational and very individual physiological wellness status. For future studies, it may be better to consider using a common comparative HR measurement to give the same set of wellness levels that negate individual health characteristics.

Fuzzy Logic Deployment in Alert System Design

Based on variable input in Table 5 and variable output in Table 6, a fuzzy set was developed for each variable using MATLAB Fuzzy Logic Experts version 2017a. The membership Function of each variable input and output defined as shown on Fig. 9 to Fig.13 below.

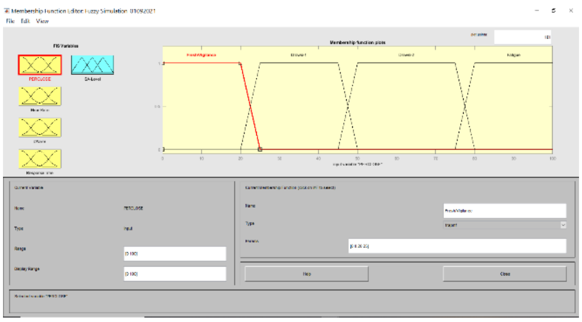

Figure 9. PERCLOS Membership Function

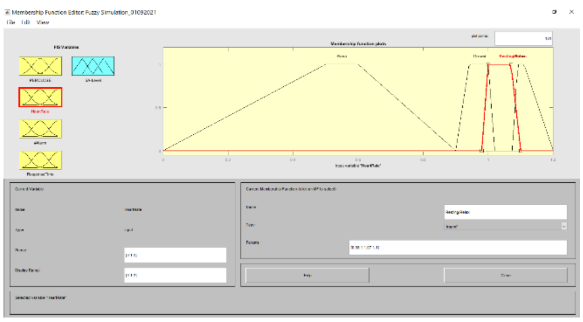

Figure 10. Heart Rate Membership Function

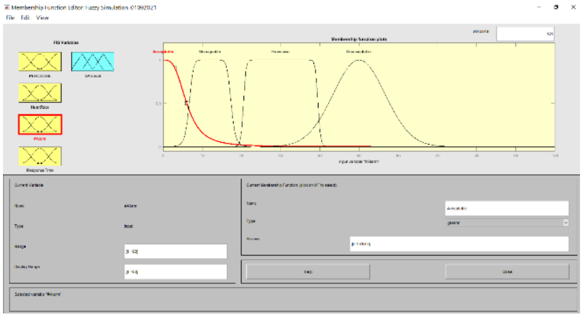

Figure 11 Alarm Membership Function

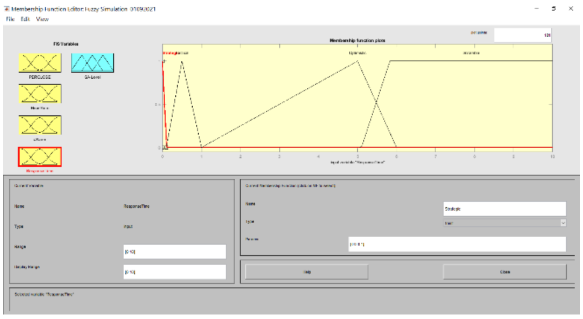

Figure 12. Response Time Membership Function

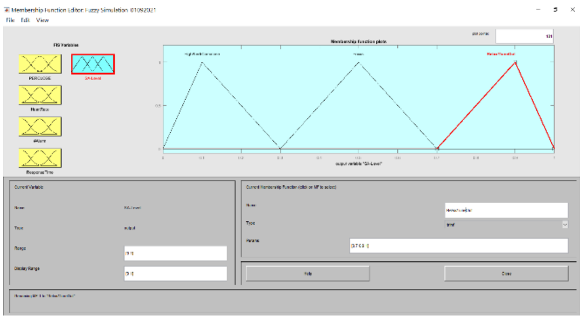

Figure 13. Situation Awareness Membership Function

Upon confirming the variable membership functions, the Fuzzy Rule set is defined as a collective function combination of each category set for variable membership function according to the following “IF X AND Y THEN Z” algorithm, for example:

IF (PERCLOS is Fresh/Vigilance)
AND (Heart Rate Ratio is Resting Relax)
AND (AM Performance is Acceptable)
AND (TS Performance is Strategic)
THEN (SALevel is Relax/Tune out)

For the research study, 156 fuzzy set rules generated by the MATLAB Simulation Software were used to develop an alert that connected to the Situation Awareness Level of the control room operator for different sets of variable input from the measurement of PERCLOS, Heart Rate, #Alarm, and Response Time of the object control room operator.


Figure 14. Rule Viewer Fuzzy Simulation Result

Figure 14 illustrates how the fuzzy logic will work and easily interfaced with the Human Machine Interface system and further provides an alert to the control room operator himself or their supervisor for further intervention or self-correction accordingly.

Illustration explanation:
Input Variable
PERCLOS = 23.5% Closure – Fatigue /Drowsi-1
Heart Rate = 1.04 of HRR – Normal Alert
#Alarm = 3.79 per 10 minutes – Manageable/Excessive Demanding
Response Time = 0.385 minutes – Tactical
Output Variable
Situation Awareness Level = 0.851 – Relaxed Awareness (Level-3 SA)

Based on the simulation result, the fuzzy logic is perfectly fit to be used as an interpretation model to measure the Situation Awareness.

The main focus of the study is to find the relationship and correlation between the physiological variable and cognitive behavior of CROs while executing their daily work, as an input to the system alert model, which will contribute to human factor excellence in the oil & gas and petrochemical industries in specific and commonly in the manufacturing industries. PERCLOS (%-closure of eye) measured using a face recognition algorithm using a camera. At the same time, the heart rate of the CRO was recorded to see the impact of psychological and mental activities while executing their tasks on their physical heart-pumping characteristic. Combined the two-measurement of the CRO represent physiological wellness. In addition to physiological wellness, CRO response time in anticipating or intervening to the process control changes from abnormal condition started to the point of control recorded as cognitive behavior. Meanwhile, the record of process alarms per 10 minutes during the observation period was noted as a performance indicator of the control and monitoring activities results. The collected record of PERCLOS, Heart Rate, Response Time, and #Alarm was tabulated for data analysis purposes. After several attempts to trend the data, it decided to choose a multiple regression method to develop a multivariable linear model.

The result of the statistical multiple regression model for the individual set of observations as well as the aggregate set of observations provides a significant correlation between independent variables mainly for PERCLOS and Response Time with statistical p-value <0.05. Heart Rate correlation was found to vary between the set of observations, where 5 out of 9 sets of observation provide a p-value slightly higher than 0.05. This anomaly was expected as the level of heart rate of an individual changes depending on the psychological environment and healthiness of the CRO by the external factors outside the workplace including moody personality. From the physical situational observation note, the set of data is consistent in that personal state at work provides abnormal data trends which then impacts the regression result. To avoid this personal situation, there is a normalization process to be treated in the raw data. In general, the result of observation supports the use of the selected variables as an input to measure CRO wellness and situation awareness level.

The findings are sufficient to step further for developing a design of a Situation Awareness Alert System embedded into Human Machine Interface in the oil & gas and petrochemicals industry. This will become a breakthrough concept of a human factor improvement area in conjunction with the worker's Health and Safety Prevention model to provide early human error prevention and to protect the industries from vulnerable catastrophic incidents.

Having demonstrated the significant variable correlation, a model of the functional system is required to process and interpret the variable input into proper messages where an individual or/and another stakeholder in the operating group can initiate a proper action or intervention to improve the situation awareness level of the CRO. After reviewing several functional system applications and the platform available in the market, Fuzzy Logic Experts has been selected for this study to simulate and interpret the selected input variable for the CRO Situation Awareness level. Based on the generated 156 fuzzy rules, the simulation is perfectly run with consistent output correlated to the set of situation awareness level definitions.

As an internal critique, ideally, the work is to be completed till a prototype design, however, due to a shortage of resources the study has been completed up to functional system application modeling which has been sufficient to demonstrate the model design is workable. This is a notice for the next research.

Conclusion

The research study was inspired by the fact that oil & gas and petrochemical industries are still suffering and facing huge losses from plant incidents. The concern about a high percentage of main root causes of incidents triggered by human error brought an idea to look in specific into the control room operator roles and responsibilities in carrying out their tasks and duty as central players in the team to monitor, maintain, control and manage operation activities in every 12 hours shift work schedule.

From the research study result, it can be concluded the following 3 points:

(1) The role of the control room operator and their contribution to the safe plant operation is very critical and crucial. Maintaining high situational awareness is mandatory.
(2) PERCLOS, Heart Rate, Response Time, and #Alarm have significant correlation and deserve to be selected as variables to monitor the wellness of CRO as well as to use as input to situation awareness and wellness alert system devices.
(3) Fuzzy Logic Expert works very well to interpret the impact of observation variables on the situation awareness level and can be deployed as a functional tool for situation awareness and wellness alert system devices.

Bibliography

Aeberhard-Hodges, J. (2019). Practitioner perspective Women and international treaty making–the example of standard setting in the International Labour Organization. In *Research Handbook on Feminist Engagement with International Law* (pp. 286–304). Edward Elgar Publishing.

Campbell, F. J. (2021). Human factors: The impact on industry and the environment. *Natural Resources Management and Biological Sciences*, 1–14.

Hadwiger, F. (2018). Contracting international employee participation. *Global Framework Agreements, Cham: Springer*.

Kurnia, L. (2016). Model Log-Linear Pada Faktor Yang Mempengaruhi Berhenti Studi Mahasiswa. *Sambutan Ketua Panitia*, 155.

Mikelsten, D. (2019). *Otomasi dan Teknologi Berkembang* (Vol. 3). Cambridge Stanford Books.

Panel, 2014 Organic Contamination, Summons, R. E., Sessions, A. L., (co-chairs), Allwood, A. C., Barton, H. A., Beaty, D. W., Blakkolb, B., Canham, J., & Clark, B. C. (2014). *Planning considerations related to the organic contamination of martian samples and implications for the Mars 2020 rover*. Mary Ann Liebert, Inc. 140 Huguenot Street, 3rd Floor New Rochelle, NY 10801 USA.

Rozo, E., Rykoff, E. S., Abate, A., Bonnett, C., Crocce, M., Davis, C., Hoyle, B., Leistedt, B., Peiris, H. V, & Wechsler, R. H. (2016). redMaGiC: selecting luminous red galaxies from the DES Science Verification data. *Monthly Notices of the Royal Astronomical Society*, *461*(2), 1431–1450.

Sakti, A. R. P., & Setiyawan, P. (2024). *Sistem Manajemen Keselamatan Dan Kesehatan Kerja K (3) Pada Proyek Pembangunan Gedung Hotel Santika Nagrak Sukabumi*. Universitas Islam Sultan Agung Semarang.

Skarphéðinsson, J. I., & Mohan, V. (2017). *Expanding the customer base for DCS in the Oil, Gas & Chemicals market in Sweden; A Case Study of ABB*.

Tanjung, K., & Nasution, M. K. M. (2005). Rancangan dan penerapan kontrol logika kabur untuk industri. *Jurnal Sistem Teknik Industri*, *6*(2), 75–78.

Wibowo, A. (2023). Internet of Things (IoT) dalam Ekonomi dan Bisnis Digital. *Penerbit Yayasan Prima Agus Teknik*, 1–94.

Winarsunu, T. (2008). *Psikologi keselamatan kerja*. UMMPress.