Failure Modes and Effects Analysis (FMEA) in Indonesia's Construction Project through Lens of Improvement and Decision-Making Strategy

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Abstract

Construction project within construction industry is deemed as high process industry through its perspectives of reliability and quality. Therefore, misconduct of the execution in this industry plays vital role of generating wide array of accidents and diseases. On empirical perspectives and on Indonesia's Construction project the risk intertwines wide spectrum of activities and processes. To some extent, it requires improvement and decision-making strategy. Subsequently, on theoretical perspectives, the risk mitigations in construction industry have been implemented. To begin with, failure modes and effects analysis (FMEA) is deemed conventional method in proceeding vis-à-vis construction industry. Furthermore, FMEA is followed by other methods, e.g., FTA, known as fault tree analysis; ETA, identified as event tree analysis. Ultimately, there are HAZOP study, as refer to hazard and operability study, and root cause analysis. The objective of this paper is to harness the theoretical and empirical perspectives of FMEA through the lens of improvement and decision-making strategy, within Indonesia's construction project. In term of improvement strategy, FMEA contributes not only to improvement strategy but also in failure risk reprioritization within FMEA methodology. Precisely, this FMEA methodology, is using index of risk priority number, namely RPN, through trilogy of detection ability (D), occurrence (O), and severity (S). In term of decision-making strategy, FMEA contributes to lean and sustainability concept, to some options of reducing waste with goal of augmenting productivity and enhancing customer's value proposition. This paper refers to the FMEA's improvement and decision-making strategy in both theoretical and empirical perspectives within Indonesia's construction project and its relevant research methodology. Ultimately, this paper elaborates integrated FMEA within bibliometric analysis as the result of Venn Diagram's Intersection among functional FMEA, process FMEA and design FMEA.

Keywords
Failure modes and effects analysis, Improvement, Decision-making strategy, Risk priority number, Lean and sustainability

1. Introduction
This paper elaborates the empirical perspectives of Indonesia's construction project within construction industry. This industry is characterized with its high process industry through its perspectives of reliability and quality. Therefore, this industry requires high anticipation and prevention as risk mitigation vis-à-vis accidents and diseases (Bas, 2022). The FMEA, was intended for manufacturing industry, and deemed semi quantitative approach. This approach is characterized through its capability to identify failure modes and effects of a system function (Towler and Sinnott, 2022).

Throughout the years, the FMEA has been applicable in construction industry, as elaborated in this paper. Commencing from an end event vis-à-vis a tree structure, the FTA relates the incidents dots that trigger upper-level ones in form of AND or OR portal. Once the fault tree is finished and identified, subsequently the possibility of the end event might be retrieved by assigning probability values to every incident at subsequent level. Meanwhile, the HAZOP study is characterized by its risk determination in term of process operability in processing industry. To some extent it furthermore embarks on potential hazards that are derived from the deviations within design requirements.
Scholar (Crawley, 2020) elaborated the differences of FTA and ETA. To begin with, ETA proceeds with a selected initiating event, e.g., failure, and its possible outcomes within a tree structure. To some extent ETA is deemed as a qualitative analysis as FTA. If probability is assigned to its possible outcomes, the ETA is deemed as a quantitative method Ultimately, other than those FMEA, FTA, ETA and HAZOP study, there is root cause analysis, through its identification of 5 consecutive whys and fishbone diagram, namely Kaoru Ishikawa diagram (Subramanian, 2021).

2. Literature Review
2.1. Failure Modes and Effects Analysis (FMEA)
FMEA, throughout the years, has been deemed vital aspects and significant dimension, as improvement strategies vis-à-vis performance in both product and service (Alruqi, David Branson III, Farndon, 2021). To some extent, the improvement strategies are applicable for construction industry, as the center stage of discussion of its empirical perspectives in this paper.

To arrive at the targeted performance, FMEA is implemented gradually within itinerary of six stages in Figure 1. To begin with, it starts with 1. Identification of functional requirement; subsequently, 2. Identification of failure modes; 3. Identification of causes-effects and control actions; 4. FMEA analysis; 5. Failure mitigation; and 6. FMEA review (Carlson, 2012).

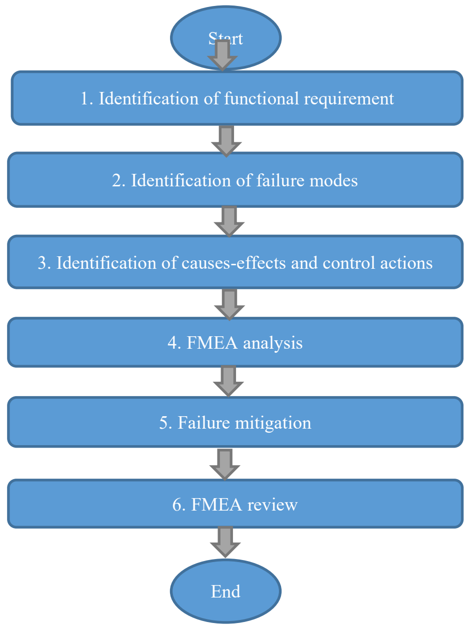

Figure 1 Six Stages Process in Implementing FMEA

2.2. Risk Priority Number (RPN)

Risk priority number (RPN) is known for its wide array of approaches, and its significant vehicle to evaluate critical factor of not only failure modes and effects analysis, namely FME; and failure modes and effects criticality analysis, known as FMECA. Within the category of conventional approach of FMECA, the RPN is deemed important in rank determination of failure modes, along with its drawbacks and weaknesses (Ciani et al. 2019).

By its original perspectives, risk priority number, namely RPN, is obtained as the result of multiplication of the Occurrence (O), Severity (S) and Detection (D) of a failure parameter. To begin with, Occurrence (O) is defined pertaining the probability in which a failure mode happens that relate to equipment's failure rate. Furthermore, Severity (S) is defined as failure strength impact on the system, in which it has relevancy with failure modes effect. Subsequently, Detection (D) indicates the possibility of diagnosing the failure mode before its effects are manifested on the system (Ciani and Venzi, 2018).

$$RPN = O \cdot S \cdot D \tag{1}$$

RPN's values ranges are based upon parameters' measurement dimension. The suggested parameter refers to IEC-60812 [4], in which O, S and D are commonly measured on a 10-point scale. To some extent, greater O and S numbers indicate the augmentation of frequency values of the frequency and its severity respectively. Meanwhile, D is ranked in a reversers order, as the probability of failure mode of higher the detection value and the lower the detection. Ultimately, in brief, the overall RPN values are within the values from 1 to 1000 (Catelani et al, 2016).

To some extent, RPN formula is deemed significantly rudimentary and intuitive, but it is beneficial for process failure's critical analysis. The RPN values are not continuous, instead it has unique values. In case, 10 values scale is merely utilized, then the range is considered empty 88%. At this point, the largest number is 1000, while 900 is deemed the second-best number. Under the prior two number, then other numbers are 810, 800, 729 and 720 (Braband and Griebel, 2014).

To revamp and improve the conventional RPN, then, Braband and Griebel proposed alternative risk priority number, namely ARPN. ARPN constitutes a modified version of the conventional RPN with the objective of providing enhanced consistent assessment of criticality in the event where parameters can be quantified on a logarithmic scale as illustrated in Table 1.

Table 1 Alternative approaches to troubleshoot conventional RPN issues

Issues	Alternative approaches
Holes	- Sum O, S and D
Duplicate RPN	- Introduction of corrective factors
	- Using exponentiation or
	Exponential function
	- Scale reduction
	- Fuzzy theory
High sensitivity	- Sum O, S and D
Importance O, S, D	- Introduction of corrective factors
	- Different formulation of RPN
	- Fuzzy theory
Subjectivity O, S, D	- Fuzzy theory
Dispersion	- Logarithmic equation
	- Sum O, S and D.
	- Scale compression

$$ARPN = IRPN = O + S + D \tag{2}$$

Improved risk priority number, namely, IRPN conveys assumption; the integer values from 3 to 30. As the result, its RPN has no gaps at all, to provide sensitivity solutions. To some extent, IRPN is highly accentuated, to generate frequency repetition of 75, as the maximum value. This value equals to the threefold bigger than the conventional RPN.

2.3. Lean Construction and Sustainability

The terminology of lean is originated from prior development in 1990s from the Toyota Production System, namely TPS, that is transformed into strategy adoption development (Sarhan et al, 2017). This strategy adoption is intended to increase efficiency of production and consumption within goods and services perspectives according to the industry categories (Ahrens, 2006; Howell and Ballard, 1998; Womack and Jones, 2003). Lean concept is coined during Fredrick Winslow Taylor's Theory. Subsequently, this concept is amplified with Henry Ford's conveyor belt invention that embarks vis-a-vis mass production during in the 19th century (Vieira and Cachadinha, 2011).

This paper elaborates the original lean terminology and develop its empirical perspectives within lean construction. This lean construction contributes the enhancement of production effectiveness as it is applied in construction industry (Howell, 1999). Subsequently, the mentioned lean construction generates the 5 (five) frameworks for lean thinking that was meticulously initiated by several scholars (Womack and Jones, 1996). 1st, customer perspectives constitute construction value's identification; 2nd, delivery measurement depicts the value streams; 3rd, waste removals are determined by various processes within workflow processes. Subsequently, as 4th, material delivery is not allowed through system, in which pull production is applied. Ultimately, continual systems and processes improvements are implemented within consistent manner. As the holistic approaches, these 5 frameworks constitute common spirit flow (Kumar et al., 2013).

Furthermore, this paper elaborates not only the lean and lean construction, but also sustainability in construction industry. As of now, sustainability challenges, since 1990s, in the construction industry constitutes long winded debates among scholars, research, and practitioners. To some extent, the construction industry in this paper refers not only to the ecosystems and infrastructure, but also any relevant construction in construction projects (Bosher et al., 2007).

The sustainable construction (SC) terminology was coined by Fernandez-Sanchez & Rodriguez-Lopez (2010). This SC is defined as being tactically developed within center stage on buildings. Eventually it is developed for civil engineering area. Another scholar, namely Khalfan (2006) defined sustainable construction as a process that is conducted through framework Triple Bottom Line, known as TBL, to generate a sustainable outcome. Ultimately, it is intended to encompass an environmental accountability, social responsibility, and economic benefit.

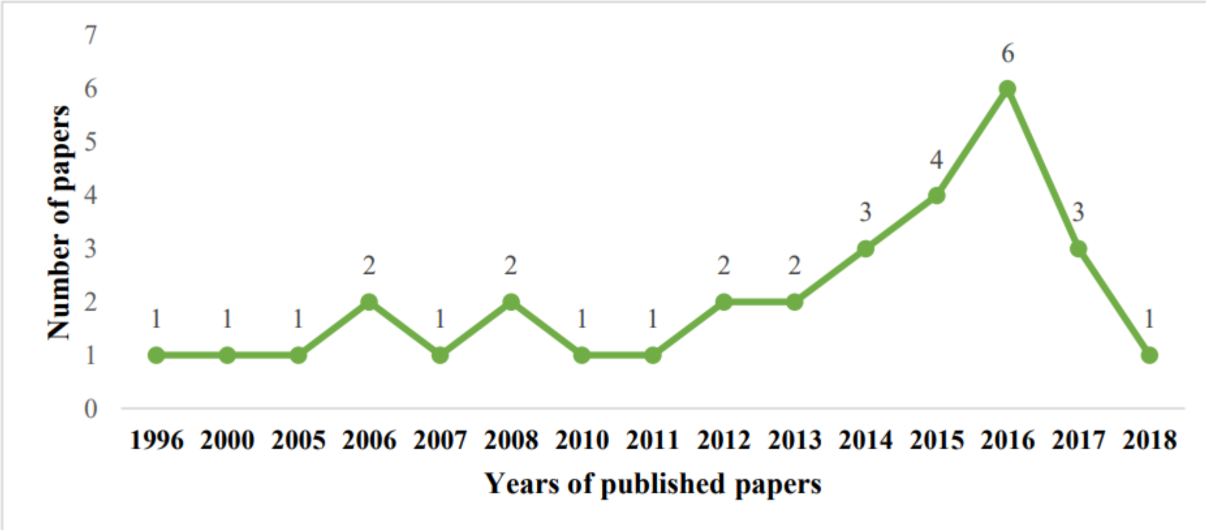

Figure 2. Systematic Literature Review of Related Publication in Construction Industry and Sustainability

Figure 2 indicates the development and the fluctuation of related publication as the result of systematic literature review, in construction industry and sustainability, in addition to engineering, manufacturing, business, energy, sustainability and geographical related journals (Misopoulos, 2019). The triple bottom line in construction projects constitutes the references and assessment to determine the sustainability factors and practices throughout the years as it is depicted in Figure 2.

3. Methods

Precisely, in this paper, The FMEA applies parameters that are coined by Cavaignac and Uchoa (2018). These parameters have the purpose of diminishing subjectivity in choosing severity, occurrence, and detection indices. To anticipate this subjectivity, their values are varied from 1 to 10 from their reality to the failure. These values are further depicted in Table 2.

Table 2 FMEA Methods: RPN Perspectives for Occupational Safety Parameters

Severity (S)		Occurrence (O)		Detection (D)	
Index	Consequence of failure	Index	Accident nature	Index	Detection methods
1	No real impact	6	Impact suffered	1	Visual inspection
2	Irrelevant trauma	5	Drop with level difference	2	Tactile test/Manual test
3	Trauma requiring first aid	5	Impact against	3	--
4	Temporary incapacity without remoteness	5	Excessive or inappropriate effort	4	--
5	Temporary incapacity with large remoteness	5	Pressing or imprisonment	5	Checklist/sequence of tests before
6	Temporary incapacity with large remoteness	5	Fall of the same level	6	--

7	Partial permanent disability	4	Noise exposure	7	--
8	Total permanent disability	4	Contact with harmful substance	8	Instrumental inspection/mechanical test
9	Death of those involve in process	4	Electric shock	9	--
10	Death of those not involved in the process	3	Friction or abrasion	10	Lack of effective methods
	--	3	Contact with extreme temperature	--	--
Source: Cavaignac e Uchoa (2018)					

The Severity (S) value of each failure, as indicated in Table 2, is the selection result within the worst situation. Meanwhile, the more approaching reality is furthermore depicted in the literature review. Furthermore, the Occurrence (O) considering Statistical value analysis as the reference of the value. Ultimately, the Detection (D) is determined by on site visits and interactions with subject matter expert of the field condition.

4. Data Collection

This paper refers to one of Indonesia's construction projects in which it is managed through project management, including its data collection. Precisely this project commences in February 2021, with estimated time to finish by the end of July 2022.

To enhance the accuracy and the wider perspectives on the process, the interview and survey stages have been conducted 6 months prior the project commenced. The interview and survey stages are conducted through purposive sampling, in which subject matter expert, e.g., related project's stakeholders. Precisely, those stakeholders comprise project managers level, including their subordinate as project supervisors and their foremen. As consideration on stakeholders' perspective, there are plan of using 153 workers within the stakeholder and related subject matter expert.

5. Results and Discussion

Based upon the risk priority number, namely RPN; this paper conveys and elaborates the results and discussion of MEA within the perspective of RPN according to actual result of the mentioned project in this paper. Precisely, this paper refers to the value of Severity (S), Occurrence (O) and Detection (D) as illustrated in the respective following Table of 3, 4 and 5. Ultimately, Table 6 provides summary of the concluded RPN.

Table 3. RPN in term of Severity (S) values

Stakeholders' position:	***Project Manager***	**Supervisor**	**Field Inspector**
***Severity* (S)**			
Delay in material arrival	5	5	5
Unavailable material stock in domestic factory	5	5	5
Material quality does not comply standard	4	5	4
Weather condition	3	4	4

Structural work process is disrupted	4	5	4
Workers' clumsiness	2	3	3
Storage and usage of material or tools are not complying standards	3	4	3
Lack of coordination among distributors	2	2	3
Additional cost to purchase material	4	4	4
Unintentional damage	3	4	4
Undiscipline workers	3	3	2
Security device malfunctional	2	5	4
Idle workers	2	2	2
Working accidents	2	2	2

The value of Severity (S) is referring to table 2 on the interpretation of each index. To some extent, the value of S values in Table 3 is ranging from 1 until 4. Precisely, value 1 means: no real impact; value 2 means: Irrelevant trauma; subsequently value 3 means: Trauma requiring first aid. Ultimately, value 4 means: temporary incapacity without remoteness. Thus, these S values does not reach S values of 5 until 10; in which value 5 means: temporary incapacity with large remoteness, while value 10 means: death of those not involved in the process.

Table 4. RPN in term of Occurrence (O) values

Stakeholders' position:	***Project Manager***	**Supervisor**	**Field Inspector**
***Occurrence* (O)**			
Delay in material arrival	3	3	2
Unavailable material stock in domestic factory	4	4	4
Material quality does not comply standard	3	2	2
Weather condition	3	4	4
Structural work process is disrupted	3	4	4
Workers' clumsiness	3	2	2
Storage and usage of material or tools are not complying standards	3	2	2
Lack of coordination among	2	2	1

distributors			
Additional cost to purchase material	3	3	3
Unintentional damage	4	4	4
Undiscipline workers	2	1	2
Security device malfunctional	1	1	1
Idle workers	1	1	1
Working accidents	2	2	2

The value of Occurrence (O) is referring to table 2 on the interpretation of each index. To some extent, the value of O values in Table 4 is ranging from 1 until 4. In other words, those values do not equal value of 5: Drop with level difference, impact against, excessive or inappropriate effort, pressing or imprisonment, fall of the same level. Similarly, those values do not equal value of 6: impact suffered.

Table 5. RPN in term of Detection (D) values

Stakeholders' position:	***Project Manager***	**Supervisor**	**Field Inspector**
***Detection* (D)**			
Delay in material arrival	1	2	1
Unavailable material stock in domestic factory	1	1	2
Material quality does not comply standard	3	3	4
Weather condition	4	5	5
Structural work process is disrupted	2	2	2
Workers' clumsiness	4	5	5
Storage and usage of material or tools are not complying standards	2	1	3
Lack of coordination among distributors	2	2	2
Additional cost to purchase material	1	2	1
Unintentional damage	2	3	1
Undiscipline workers	2	2	1
Security device malfunctional	3	2	3
Idle workers	4	2	2
Working accidents	3	1	1

The value of Detection (D) is referring to table 2 on the interpretation of each index. To some extent, the value of S values in Table 5 is ranging from 1 until 5. Precisely, value 1 means: visual inspection; value 2 means: tactile test/Manual test; subsequently value 3 and 4 means: value between 2 and 4. Ultimately, value 5 means: checklist/sequence of tests before, until the value of 10 means: lack of effective methods.

Table 6. RPN in overall values

Risk	***Severity*** **(S)**	***Occurrence*** **(O)**	***Detection*** **(D)**	**RPN**
Delay in material arrival	5	2,7	1,3	17,55
Unavailable material stock in domestic factory	5	4	1,3	26
Material quality does not comply standard	4,3	2,3	3,3	32,63
Weather condition	3,7	3,7	4,7	64,34
Structural work process is disrupted	4,3	3,7	2	31,82
Workers' clumsiness	2,7	2,3	4,7	29,18
Storage and usage of Material or tools are not Complying standards	3,3	2,3	2	15,18
Lack of coordination among distributors	2,3	1,7	2	7,82
Additional cost to purchase material	4	3	1,3	15,6
Unintentional damage	3,7	4	2	29,6
Undiscipline workers	2,7	1,7	1,3	6
Security device malfunctional	3,7	1	2,7	10
Idle workers	2	1	2,7	5,4

Working accidents	2	2	1,7	6,8

From Equation (1), the value of RPN is RPN = O · S · D. For example, for Risk of Delay in material arrival, O =5; S= 2,7 and D=1,3. It results in RPN value of 17,55

5.1 FMEA and Improvement Strategy in Construction Industry

To some extent, FMEA is beneficial in improvement strategy in wide array of product, manufacturing, and service industry. Within FMEA perspective, two significant aspects play vital role in applying improvement strategy, which are RPN and the economic metrics, and are applicable in Indonesia's construction projects within construction industry. These metrics include the following but not limited to money, time, and quality specifications.

Precisely, in term of product and manufacturing industry, FMEA's implementation strategies are based upon criteria A: economic within 1st, application context of supply chain (Pujawan and Geraldine, 2009); and 2nd, application context of company's empirical application (Karupusamy et al. (2006), Carmignani (2009), Childs (2009), Hekmapatnah et al. (2009), Niu et al. (2009)). In addition to the economic criteria, FMEA is applicable within the criteria B: RPN. 1st, it refers to the RPN's application context of supply chain based upon scholars' empirical research (Sinha et al. (2004) and Teng et al. (2006)). Meanwhile, other than supply chain, there are RPN's application context of company's empirical application based upon other scholars' empirical research (Bluvband et al. (2003) Yadav et al. (2003), Arvanitoyannis and Varzakas (2009).

Furthermore, in term of service industry, FMEA's implementation strategies are based upon criteria C: economic, and it elaborates merely the application context of company's empirical application based upon scholars (Seyedhosseini and Hatefi (2009), Seyedhosseini et al. (2009)). Similarly, FMEA's implementation strategies are applicable based upon criteria D: RPN in supply chain's application context (Kumar (2010) and Kumar et al. (2009)), and in company's empirical application based upon scholars (Nassimbeni et al. (2012), Cicek and Celik (2013)).

5.2 FMEA and Decision-Making Strategy in Construction Industry

This paper is entitled: Failure Modes and Effects Analysis (FMEA) in Indonesia's Construction Project through Lens of Improvement and Decision-Making Strategy. Thus, in addition to discuss in session 5.1 on Improvement Strategy, subsequently this paper discusses Decision-Making Strategy. Precisely, in addition to implement improvement strategy, then, the Indonesia's construction project, as elaborated in this paper proceed to implement decision-making strategies. The mentioned decision-making strategy is not merely on the prior discussion of economic and RPN criteria; but also, the one of choosing not only RPN, but also the available FMEA methods, e.g., Fault Tree Analysis (FTA), or, Event Tree Analysis (ETA), or Hazard and Operability (HAZOP) study, and root cause analysis.

As one of the important remarks, the choice of RPN and the data as results of RPNs in Table 3, 4, 5 and 6 determines the decision-making of Indonesia's construction project in this paper.

Subsequently, in addition to proceed appropriate decision-making, the decision-making strategy in this paper, intertwine with the lean construction and sustainability. Thus, empirically, this paper of Indonesia's construction project, elaborates the decision-making strategy that enable managers and practitioners to select the appropriate lean construction projects for implementation.

6. Conclusion

Construction project within construction industry is deemed as high process industry through its perspectives of reliability and quality. Therefore, misconduct of the execution in this industry plays vital role of generating wide array of accidents and diseases. On empirical perspectives and on Indonesia's Construction project the risk intertwines wide spectrum of activities and processes. Furthermore, on theoretical perspectives, this paper emphasizes its literature review based upon, in session 2 of literature review, but not limited to the following trilogy of 1st: Failure Modes and Effects Analysis including its 6 stages framework; 2nd: Risk Priority Number (RPN) including its parameters of Occurrence, Severity and Detection; and 3rd: Lean Construction and Sustainability within the perspectives of Triple Bottom Line, known as TBL.

This paper elaborates the fact that FMEA and its improvement strategy is beneficial not only for product and manufacturing, but also vis-à-vis service industry. This paper emphasizes this benefit for application in Indonesia' construction projects within construction industry. FMEA and its decision-making strategy is beneficial for decision-making strategy not merely on the prior discussion of economic and RPN criteria; but also, the one of choosing not only RPN, but also the available FMEA methods, e.g., Fault Tree Analysis (FTA), or, Event Tree Analysis (ETA), or Hazard and Operability (HAZOP) study, and root cause analysis.

The choice of RPN and the data as results of RPNs as depicted in Table 3, 4, 5 and 6 in this paper, determines the decision-making of Indonesia's construction project in this paper.
It is deemed important to highlight that the empirical perspectives of Indonesia's construction project in this paper intertwines with the lean construction and sustainability. Thus, empirically, this paper of Indonesia's construction project, elaborates the decision-making strategy that enable stakeholders, for the following positions and beyond e.g., managers and practitioners to select the appropriate lean construction projects for implementation.

Biographies

Hwi-Chie Ho is a professional engineer in Industrial Engineering and an associate professor in Industrial Engineering Department at Bina Nusantara University. She currently serves as the Dean of BINUS ASO School of Engineering. Previously, she was the Dean of the Faculty of Engineering (2009-2014). Her research and lectures revolve around ergonomics, quality, and industrial psychology. As a professional member of the Institute of Industrial and Systems Engineers (IISE), she has been dedicating her quality time to supporting the IISE BINUS University Student Chapter #716 as the faculty advisor, resulting in the continual achievement of the Chapter's Gold Award ever since its establishment (2012-2020). She received an outstanding faculty advisor award from the IISE for Southeast Asia Regional Winner in 2016, 2018, 2019 and Asian Regional Winner in 2017 and 2020. She is also a fellow in Industrial Engineering and Operations Management (IEOM) society and is actively involved in numerous IEOM conferences. Concurrently, her previous working experience as a notable CEO in the automotive industry (Audi & Volkswagen Indonesia: awarded as one of 40 best executives in Indonesia in 2002, SWA Magazine) has led her to the frequent invitation as a special guest lecturer in various leading industries.

Selvi, Gladysa Valerie, and Rick Darmawan were undergraduate IE students at Bina Nusantara University who graduated in 2021.

Khristian Edi Nugroho Soebandrija is a practitioner in the field of engineering, with study and working exposures in Europe, Asia and United States of America. Currently, he is one of lecturer specialist PhD level, in BINUS ASO School of Engineering. He has been awarded as distinguished honor membership in Sigma Gamma Tau, known as Aerospace Engineering Honor Society; and Tau Beta Pi, known as National Honor Society in USA. He is one of Institute of Industrial Engineers (IIE), in which IIE is now becoming Institute of Industrial and Systems Engineers (IISE).

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