Improving the Capacity of Espresso Machine Using Reverse Engineering Method and VDI 2221 Method

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Abstract
An espresso machine is used to extract coffee powder under high pressure. The machine works instantly as the coffee powder will be extracted through hot sprayed water. Small coffee shops who just started their business use simple machines with small capacities. In this research, the machine used is a small machine with a 1.7-liter water capacity. Through this research, the capacity will be increased, and the machine's efficiency will be improved so that small coffee shops can start their business with small capital but with maximal results. Reverse engineering is an analysis process of an existing product to be used as a reference for designing a new similar product but with improved advantages of the product. The research started with determining the topic and continued with a literature study, which will discuss and observe the work process. Reverse engineering is done by disassembling and reassembling the machine used for the benchmark, followed by modifying the machine to become a new prototype. After the modification, the machine will have higher efficiency. Previously the machine could only do eight repetitions; after the modification, it can do fourteen repetitions.

Keywords
Coffee shop, espresso machine, reverse engineering, VDI 2221.

1. Introduction
An espresso machine or coffee maker is a tool that every coffee shop business needs. The espresso machine functions to produce high-quality coffee powder extracts, which are then served as delicious coffee dishes. This tool will work instantly under high pressure as the coffee powder are extracted via hot water spray. An espresso machine consists of several basic parts.

With the increase in people's needs and desires in consuming coffee, coffee shops have an excellent opportunity to develop and fulfill people's needs and desires. Therefore, innovation is needed to improve the coffee maker's performance to meet the needs of the coffee shop. In developing the espresso coffee machine, the Reverse Engineering method is often used to improve a machine's performance. It uses the VDI 2221 design method to optimize the machine's material, technology, and economic condition.

1.1 Objectives
The problem to be discussed is how to improve the coffee machine's performance and function with a reverse engineering method approach so that the machine can better meet the needs of the coffee shop and the VDI 2221 design method approach to increase design efficiency. Therefore, this research aims to know the function of each component in the machine, increase the capacity of the coffee brewing process, and get a coffee maker design that can be assembled and applied.

2. Literature Review
Reverse engineering is the process of extracting knowledge or design blueprints from anything created by humans. This concept existed before computers and modern technology, even at the start of the industrial revolution. Reverse engineering is usually done to gain new knowledge, new

ideas, and design philosophy when the information was not previously available. This information could be owned by other people who do not want to share it or be lost or damaged. Traditionally, reverse engineering is done by physically disassembling the product to see the secrets of the design. The information obtained will be used to create similar and better-developed products. Reverse engineering often involves examining a product under a microscope by taking apart the product's components and figuring out their respective functions. A design must consider several aspects: comfort, practicality, safety / security, ease of use, ease of maintenance, and ease of repair. A design must consider feasibility, reliability, material specifications, and structure or power system based on its function. Engineers from Germany developed a product design method known as the VDI 2221 method, a systematic approach to design engineering systems and engineering products described by G. Pahl and W. Beitz. (VDI = *Verein Deutscher Ingeniure* / Association of German Engineers). This method is expected to make it easier for an engineer to master design systematics without learning in detail. Overall, the work steps contained in VDI 2221 consist of 7 stages, which are grouped into 4 phases, as follows: Clarification of the Task, Conceptual Design, Embodiment Design, and Detail Design.

This study aims to determine the function of each component in the machine, then increase the capacity of the coffee brewing process and get a coffee maker design that can be assembled and applied.

3. Methods

The research flowchart that will explain the steps taken in the research is shown in Figure 1.

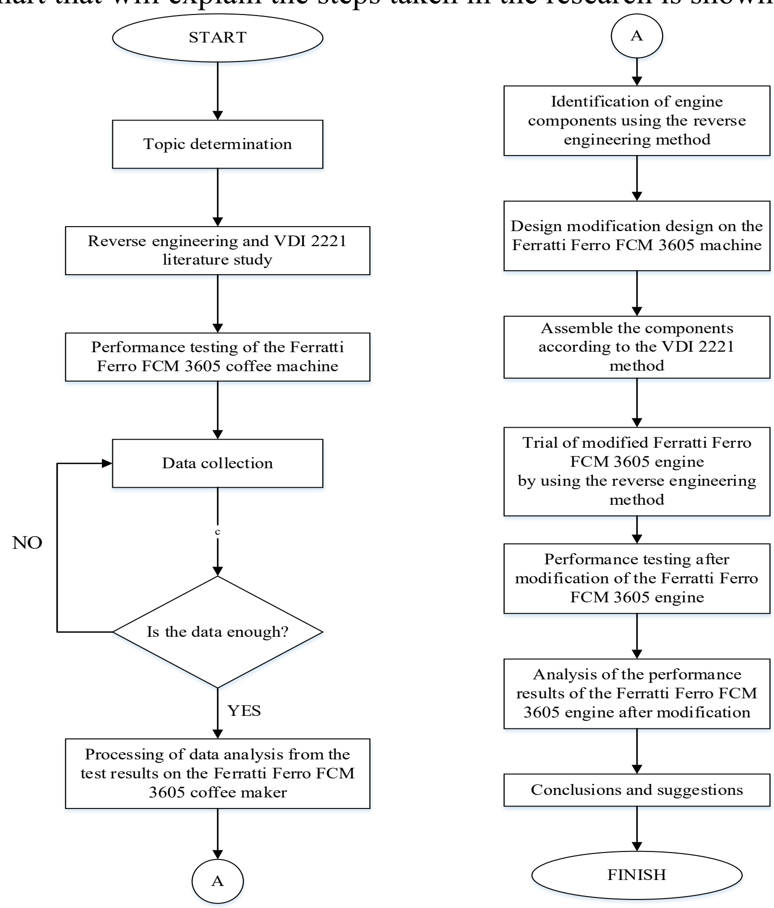


Figure 1. Research Flowchart of Modification Planning for Ferratti Ferro FCM 3605 offee Brewing Machine

4. Data Collection

Data collection will be carried out by testing on the Ferratti Ferro FCM 3605 machine. The test carried out on the machine was made with 15 grams of espresso coffee powder in 25 seconds. The experimental data seen is the yield produced; the espresso temperature right after it is brewed. It calculates the number of experiments that can be carried out with water in a fully charged water tank until the water in the water tank runs out. The experiment until the water tank ran out was carried out three times. The results and experimental data can be seen in Table 1 and Table 2.

Table 1. Experiment Results of the Ferratti Ferro FCM 3605 Brewing Machine

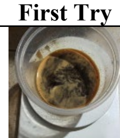
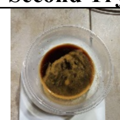
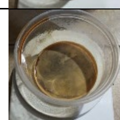
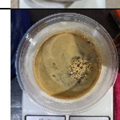
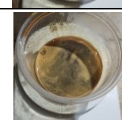
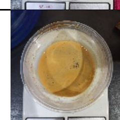
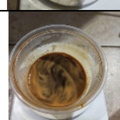
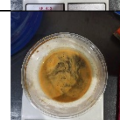
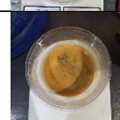
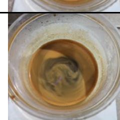
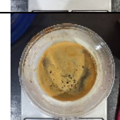
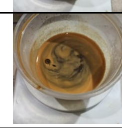
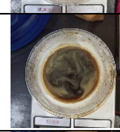
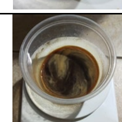
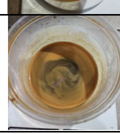
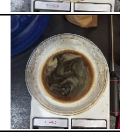
First Try	Second Try	Third Try
		
		
		
		
		
		
		
		

Table 2. Experimental Data of Ferratti Ferro FCM 3605 Brewing Machine

Tries	Coffee powder (gr)	Time (s)	*Yield* A (gr) / Temperature A (°C)	*Yield* B (gr) / Temperature B (°C)	*Yield* C (grr) / Temperature C (°C)	Water Left in Tank (gr/ml) A	B	C
1	15	25	43	45	47	1700	1700	1700
			53,4	54,2	53,2			
2			43	46	45	1533	1517	1505
			55,5	55,6	54,5			
3			44	47	46	1341	1322	1301
			57,1	56,7	56,3			
4			46	45	45	1132	1103	1121
			57,6	57,8	57,7			

Table 2 Continuation. Experimental Data of Ferratti Ferro FCM 3605 Brewing Machine

Tries	Coffee powder (gr)	Time (s)	*Yield* A (gr)	*Yield* B (gr)	*Yield* C (grr)	Water Left in Tank (gr/ml)		
			Temperature A (°C)	Temperature B (°C)	Temperature C (°C)	A	B	C
5			46	46	46	958	936	992
			57,5	57,6	57,5			
6			48	45	47	768	743	801
			57,3	57,7	57,4			
7			47	47	45	638	557	673
			57,8	58,1	58,1			
8			46	46	46	437	362	482
			58,2	58,3	58,6			
Average	15	25	Yield : 45,875			Water Left:		
			Temperature : 56,821			250	179	262

In the next stage, the Ferratti Ferro FCM 3605 machine is disassembled to obtain and analyze each product of the component's functions. The components of the Ferratti Ferro FCM 3605 machine can be seen in Figure 2.

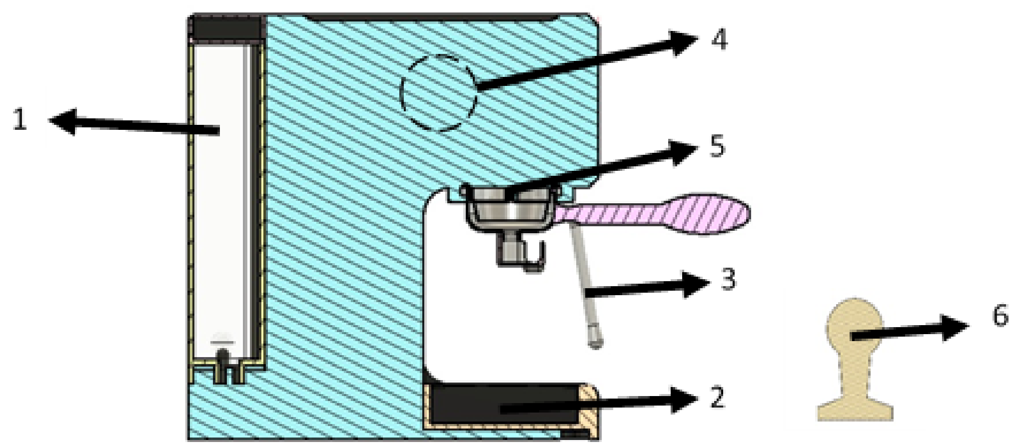


Figure 2. Components of the Ferratti Ferro FCM 3605 Brewing Machine

Description of components 1-6 in Table 3.

Table 3. Components of the Machine

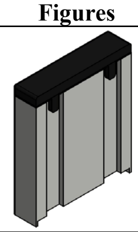
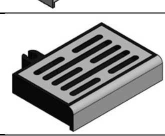
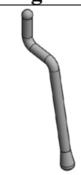
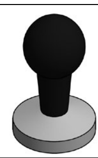
No.	Components	Figures	Descriptions	Dimension
1	Water Tank		A place to fill the water. And its function to be used to make espresso and to steam.	Length = 230 mm Width = 56 mm Height = 270 mm
2	Waste Tray		A tray at the bottom of the machine to collect water or dirt from leftover coffee.	L = 186 mm W = 127 mm H = 40 mm

Table 3 Continuation. Components of the Machine

No.	Components	Figures	Descriptions	Dimension
3	Steam Wand		A wand is used for its function to steaming milk or other ingredients.	H = 133 mm D = 4,5 mm
4	Steam Knob		Rotatable button. The steam knob functions to regulate the hot steam out of the steam wand	D = 47 mm L = 35 mm
5	Portafilter		A container that holds the coffee powder to be extracted.	L = 210 mm D = 81 mm
6	Tamper		Tool for compacting coffee powder on the portafilter.	H = 95 mm D = 58 mm

Based on the experimental results on the machine, the average yield produced with 15 grams of coffee powder and for 25 seconds is 45.875 grams, a temperature of 56.821 ℃, as well as experiments that can be carried out, is a total of eight times until the water in the water tank has to be refilled. To increase the water capacity to make more coffee and not refill it many times is to enlarge the water tank.

5. Results and Discussion

The VDI 2221 design is a method for solving problems and optimizing the use of materials. Determination of the initial specifications can be seen in Table 4.

Table 4. List of Initial Specifications

Parameter	Specification	D(Demand)/W(Wish)
Geometry	Diameter	W
	Height	W
Energy	Efficient use of electricity	W
Material	Easy to get	D
	Durable material	W
Assembly	Easy to disassemble and assemble	D
Production Cost	Affordable manufacturing costs	D

After determining the initial specifications, the sub-function solution principle needs to be made to select the components that will be used in the coffee machine's design. The variants made can be made into several variants and then analyzed intending to produce products with high efficiency values. The principle of the solution can be made as many as desired. After the sub-function solution is made, the next step is to make the possible combination to form the most supportive system. The selection of sub-function combinations can be seen in Table 5.

Table 5. Combination of Sub-Function Solution Principles

No	Principle of solution / Sub Function	Description	1	2	3
1	Water Tank	Made	Stainless Steel	Aluminum	Acrylic
2	Waste Tray	Made	Plastic	Stainless Steel	
3	Steam Wand	Bought	Stainless Steel		
4	Steam Knob	Bought	Rubber	Stainless Steel	Plastic
5	Portafilter	Bought	Stainless Steel		
6	Tamper	Bought	Stainless Steel	Hard Nylon	

V1 V2 V3

To determine the variant to be continued, a selection was made of the existing variants. One way of selecting variants can be done by using a selection diagram. The variant selection table can be seen in Table 6.

Table 6. Selection of Solution Variants

Selection Diagram	
Variants are Evaluated Using Solution Criteria:	Decision Mark Solution Variant (SV):
(+) Yes	(+) Improve Solution
(-) No	(-) Eliminate Solution
(?) Not Enough Information	(?) Gather Information
(!) Check Specification	(!) Check Specification for Changes

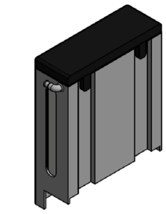
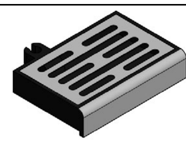
	In accordance with the overall function	In accordance with the wish list	In principle can be realized	Within the limits of production costs	Knowledge of concepts is sufficient	In accordance with the maker's wish	Meets security requirements	Description	SV
V1	+	-	+	+	+	+	+	Fit	+
V2	+	-	+	-	+	-	+	Unfit	-
V3	+	-	+	-	+	-	+	Unfit	-

Based on the variant table, it can be seen that variant 1 meets the design criteria for making a coffee machine, then variant 1 will be continued at a later stage. The selected concept drawings of the new design's front and back can be seen in Figure 3.

Figure 3. Selected Concept of the New Design

The dimensions specified in the new design can be seen in Table 7.

Table 7. Dimensions of New Design Coffee Brewing Machines

No.	Figures	Description	Size (cm)
1		Water Tank	P = 230 mm L = 84 mm T = 310 mm
2		Waste Tray	P = 186 mm L = 127 mm T = 40 mm

The changes made were to increase the water tank's capacity from 1.7 liters to 2.5 liters so that it can be used longer before it has to be refilled. Another change that was made was to add nepple component to the waste tray and to make a channel from the tray so that it could go straight down because the tray filled up too quickly. The tray is immediately full when making one espresso or a maximum of two times.

5.1 Implementation and Analysis of Improvement Result

After designing an espresso coffee machine with a reverse engineering method, then what is done is the process of implementing an espresso coffee machine with a new design to be able to see the specifications that will be obtained. Design drawings can be seen in Figure 3 and front and rear views in Figure 4. The components can be seen in Figure 5 and further described in Table 8.

Figure 4. New Design Front View (A), Rear View (B), and Top View from Rear (C)

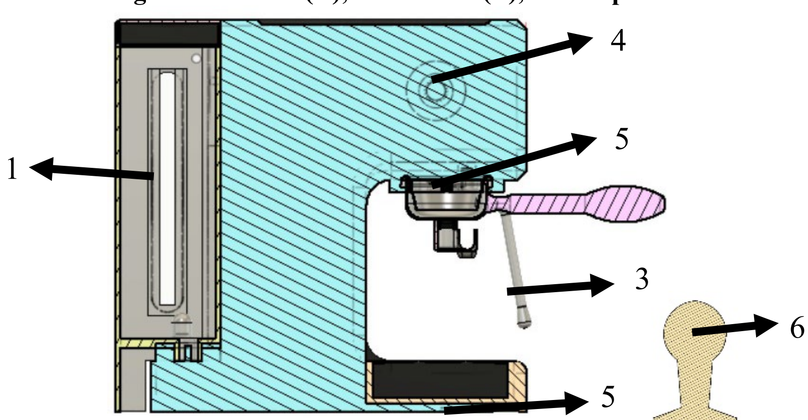
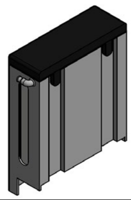
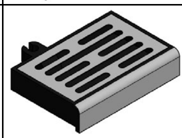


Figure 5. Components on Brewing Machines After

Description of components 1-6 in Table 8.

Table 8. Modified Coffee Machine Components after Modification

No.	Components	Figures	Descriptions	Dimension
1	Water Tank		A place to fill the water. And its function to be used to make espresso and to steam	L = 230 mm W = 56 mm H = 270 mm
2	Waste Tray		A tray at the bottom of the machine to collect water or dirt from leftover coffee.	L = 186 mm W = 127 mm H = 40 mm
3	Steam Wand		A wand is used for its function to steaming milk or other ingredients.	H = 133 mm D = 4,5 mm
4	Steam Knob		Rotatable button. The steam knob functions to regulate the hot steam out of the steam wand	D = 47 mm L = 35 mm
5	Portafilter		A container that holds the coffee powder to be extracted.	L = 210 mm D = 81 mm
6	Tamper		Tool for compacting coffee powder on the portafilter.	H = 95 mm D = 58 mm

In the next stage, a retest is carried out in the coffee brewing process. The test carried out is the same as the initial test, namely making espresso with a dose of 15 grams for 25 seconds. The thing that should be considered is how many experiments can be done after increasing the water tank's water capacity. Result data can be seen in Table 9 and Table 10.

Table 9. Modified Brewing Machine Experiment Results

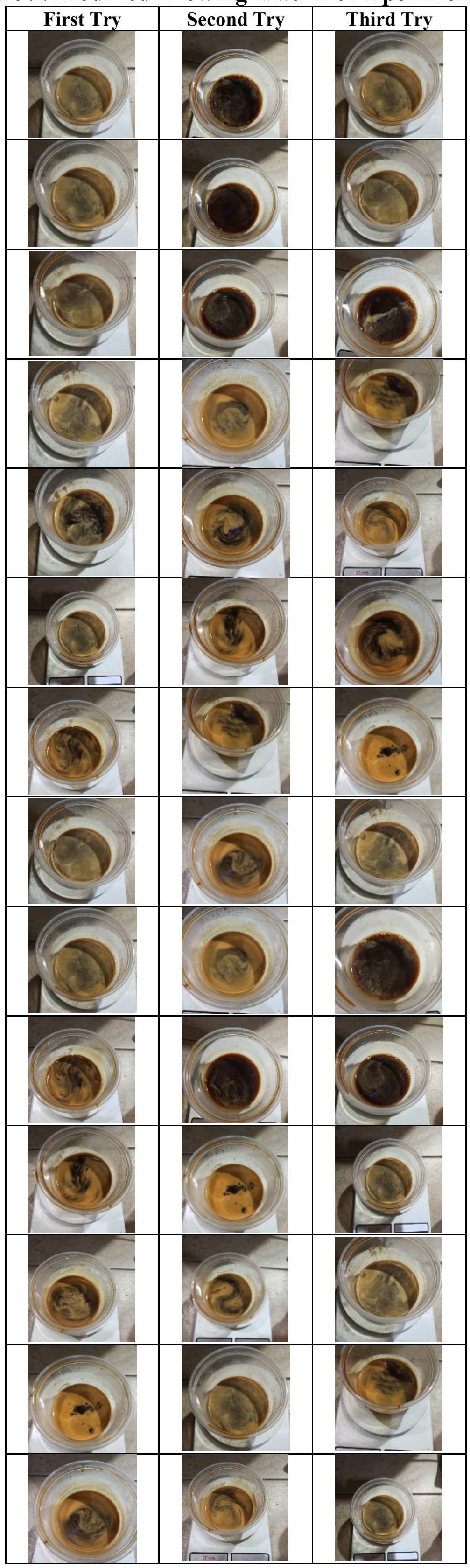


Table 10. After Modified Brewing Machine Experiment Data

Tries	Coffee (gr)	Time (s)	*Yield* A (gr)	*Yield* B (gr)	*Yield* C (grr)	Water Left in Tank (gr/ml)		
			Temperature A (°C)	Temperature B (°C)	Temperature C (°C)	A	B	C
1	15	25	45	45	44	3000	3000	3000
			54,1	54,3	53,8			
2			44	45	45	2794	2814	2807
			55,1	55	54,9			
3			46	46	45	2590	2645	2619
			56,6	56,8	56,2			
4			46	45	45	2379	2431	2404
			57,4	57,6	57,3			
5			45	46	46	2170	2260	2232
			58,4	58,6	58,1			
6			45	44	45	1969	2099	2003
			58,1	58,3	57,9			
7			44	44	45	1770	1824	1829
			58,3	58,5	58,2			
8			46	45	46	1555	1678	1613
			57,8	58,3	57,5			
9			45	45	46	1352	1490	1429
			58,5	58,9	58,4			
10			44	46	46	1141	1274	1206
			59,2	59,4	59			
11			45	45	45	917	1037	993
			59,3	59,6	59,2			
12			46	45	45	733	814	784
			60,1	60,3	59,9			
13			45	44	45	551	629	564
			60,3	60,5	60,1			
14			44	46	45	381	474	358
			60,2	60,4	60			
Average	15	25	Yield : 45,07			Water Left:		
			Temperature : 58,105			206	273	196

6. Conclusion

Based on research modifying espresso coffee makers using the reverse engineering method and the VDI 2221 method that has been carried out, it can be concluded that:

1. The first stage in designing using reverse engineering to design a new coffee machine is as follows:
   a. *Disassembly*
   b. *Assembly*
   c. *Benchmark*

   In this design, the engineering design method is used to solve problems and optimize materials, technology, and economic conditions. The engineering design method used is the VDI 2221 method. According to G. Pahl, W. Beitz, J. Feldusen, K.H. Grote (2007) states that there are four stages in the VDI 2221 method, namely:
   a. Clarification of the Task
   b. Conceptual Design
   c. Embodiment Design
   d. Detail Design.

2. Know the concepts and functions of espresso coffee makers so that testing and modification of espresso coffee makers can be carried out more efficiently and effectively.
3. Experiments were carried out using the time set on the machine, namely 25 seconds. From the results of the coffee brewing machine after modification design, it was found that the test results were quite satisfactory, namely a significant increase in water capacity. The previous machine can be used as many as eight repetitions, increasing to up to fourteen repetitions. Another improvement is in the waste tray because before modification, and the tray is filled very fast due to its small capacity. It is necessary to overcome this by connecting the tray's outlet and not to be full and immediately flowed out using the channel. This modification is very effective because it was necessary to dispose of the waste in making espresso continuously in the old design. After all, if it was not removed, the tray would be full, and the waste would spill out.
4. The changes made have increased the machine's efficiency because it dramatically shortens the time required for secondary things such as disposing of waste and filling water in the tank.

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Biography

Claudia Jessica Atmadja was born in Jakarta, Indonesia on 19th May 1999. She graduated from a highly respected high school in Jakarta, Santa Ursula Jakarta. She is currently on her last year in Universitas Tarumanagara, majoring in Industrial Engineering. She used to be a member of the student executive council, Badan Eksekutif Mahasiswa Universitas Tarumanagara, for the last two years. Since her first year, she has been a member of the UNTAR Basketball Team and had won few championships with her team. She had been a lab assistant for a few subjects. In 2020, she had an internship at PT. Prima Honeycomb International.

Lina Gozali is a lecturer at the Industrial Engineering Department of Universitas Tarumangara since 2006 and a freelance lecturer at Universitas Trisakti since 1995. She graduated with her Bachelor's degree at Trisakti University, Jakarta - Indonesia, then she got her Master's Degree at STIE IBII, Jakarta – Indonesia, and she recently got her Ph.D. at Universiti Teknologi Malaysia, Kuala Lumpur – Malaysia in 2018. Her apprentice college experience was in paper industry at Kertas Bekasi Teguh, shoes industry at PT Jaya Harapan Barutama, and automotive chain drive industry at Federal Superior Chain Manufacturing. She teaches Production System and Supply Chain Management Subjects. She did a research about Indonesian Business Incubator for her Ph.D. She has written almost 70 publications since 2008 in the Industrial Engineering research sector, such as Production Scheduling, Plant Layout, Maintenance, Line Balancing, Supply Chain Management, Production Planning, and Inventory Control. She had worked at PT. Astra Otoparts Tbk before she became a lecturer.

Frans Jusuf Daywin was born in Makasar, Indonesia on 24th November 1942. is a lecturer in the Department of Agricultural Engineering at Faculty of Agricultural Technology Bogor Agricultural University since 1964 conducted teaching, research, and extension work in the field of farm power and machinery and become a professor in Internal Combustion Engine and Farm Power directing and supervising undergraduate and graduate students thesis and dissertation and retired as a professor in 2007. In 1994 up to present as a professor in Internal Combustion Engine and Farm Power at Mechanical Engineering Program Study and Industrial Engineering Program Study Universitas Tarumanagara, directing and supervising undergraduate student's theses in Agricultural Engineering and Food Engineering Desain. In 2016 up to present teaching undergraduate courses of the introduction of concept technology, research methodology, and seminar, writing a scientific paper and scientific communication, and directing and supervising undergraduate student's theses in Industrial Engineering Program Study at the Faculty of Engineering Universitas Tarumanagara. He got his Ir degree in Agricultural Engineering, Bogor Agricultural University Indonesia in 1966, and finished the Master of Science in Agricultural Engineering at the University of Philippines, Los Banos, the Philippines 1981, and got the Doctor in Agricultural Engineering, Bogor Agricultural University Indonesia in 1991. He joined 4-month farm machinery training at ISEKI CO, AOTS, Japan in 1969 and 14 days agricultural engineering training at IRRI, Los Banos the Philippines, in March 1980. He received the honors "SATYA LANCANA KARYA SATYA XXX TAHUN" from the President of the Republic of Indonesia, April 22nd, 2006, and received appreciation as Team Jury from the Government of Indonesia Minister of Industry in Industry Start-Up 2008. He did several research and survey in the field of farm machinery, farm mechanization, agricultural engineering feasibility study in-field performance and cost analysis, land clearing and soil preparation in secondary forest and alang-alang field farm 1966 up to 1998. Up till now he is still doing research in designing food processing engineering in agriculture products. Up to the present he already elaborated as a conceptor of about 20 Indonesia National Standard (SNI) in the field of machinery and equipment. He joins the Professional Societies as a member: Indonesia Society of Agricultural Engineers (PERTETA); Indonesia Society of Engineers (PII); member of BKM-PII, and member of Majelis Penilai Insinyur Profesional BKM-PII.

Carla Olyvia Doaly is a lecturer in the Industrial Engineering Department at Universitas Tarumanagara graduated with my bachelor's degree from Institut Teknologi Nasional Malang, which study the Industrial Engineering program, then continued my Master Degree at Institut Teknologi Bandung majoring in Industrial engineering and management and a special field of Enterprise Engineering. I am very interested in studying industrial engineering by doing research related to System Design and Engineering, Supply Chain Management, Operations Research and Analysis, Information System Management, Occupational Health and Safety, Facilities Engineering, Quality and Reliability Engineering.

Agustinus Purna Irawan was born in Mataram - Musirawas, South Sumatera, August 28, 1971. Is a Lecturer at Universitas Tarumanagara and has served as Chancellor since 2016 until now. Obtained a Bachelor of Mechanical Engineering from the Faculty of Engineering, Gadjah Mada University (1995), a Masters in Mechanical Engineering from the Faculty of Engineering, University of Indonesia (2003), a Doctor of Mechanical Engineering from the Faculty of Engineering, University of Indonesia (2011), Professional Engineer (Ir) Mechanical Engineering from the Faculty of Engineering, Gadjah Mada University (2019) and Professor of Mechanical Engineering from the Ministry of Education and Culture (2014). The fields of scientific research and publication include: Product Design and Development, Strength of Materials, Natural Fiber Composites with implementation in the field of prosthesis and automotive components. Obtaining Research and Community Service Grants for Higher Education / Research and Technology BRIN / Untar / Others ≥ 100 titles; Patents: 7 and still in process: 4; Copyright: 9 books; Textbooks: 6 books; Book Chapter: 2 chapters; Scientific articles ≥ 100 titles. Obtained a Professional Certificate, namely the Educator Certificate, the Intermediate Professional Engineer Certificate (IPM) of the Indonesian Engineers Association (BKM PII) Vocational Engineer Association (BKM PII), and the ASEAN Engineer Certificate (ASEAN Eng.) From the ASEAN Federation Engineering Organizations (AFEO). He is active in education, various scientific activities, the world of business, professional associations, and various social activities. Received several awards: Best Graduate S2 UI GPA 4.00 cum laude (2003); First best Lecturer Kopertis Region III DKI Jakarta (2011); Best Presentation at the Seminar on Research Results of the Centralized Program, PUPT Dikti (2014); Honorary Member of The ASEAN Federation of Engineering Organizations, AFEO (2018); Best PTS Chancellor for the Academic Leader Award Program (2019).