International Journal of Advances in Applied Sciences (IJAAS)
Vol. 12, No. 1, March 2023, pp. 82~92
ISSN: 2252-8814, DOI: 10.11591/ijaas.v12.i1.pp82-92

Design and manufacture of four wheel tractor for medium size work rice farming

Iwan Harianton[1], Agus Surjana Saefudin[2], Muhammad Ali Suparman[1]
[1]Department of Manufacturing Engineering, Faculty of Manufacturing Engineering Technology, Bandung Polytechnic of Manufacturing, Bandung, Indonesia
[2]Precision Tooling Center, School of Manufacturing Engineering, Bandung Polytechnic of Manufacturing, Bandung, Indonesia

Article Info

Article history:

Received Jan 12, 2022
Revised May 19, 2022
Accepted Dec 21, 2022

Keywords:

Construction for functionality
Design for purpose
Ergonomic consideration
Medium tractor 30 HP
Unmanned control system

ABSTRACT

Indonesia is located at the equator occupy areas north and south of its bearing atmosphere where about 270 million people live the land of very rich soil and are also rich in mineral sediment demanded heavily for today's technology including nickel, bauxite, lithium, and aurum with its close articles such as thin and uranium. So numerous heavy mining equipment works around the clock. Unfortunately, the other potential products of the rich soil were somehow neglected as the nation left such activities to its traditional practice by utilizing man and animal to cultivate the plantation, so that the productivity of the land from the surface is very minimal such that the average productivity of the soil only reach 27% compared to its champion in the developed countries per acre per year. The study on such low soil productivity is caused by two main problems, such that the lack of massive soil processing technology and low attraction for the worker to pursue their career in farming as more money is offered by the transportation sector being an online transport business. This article is a series published on the tractor research initiative that aims to provide a functional medium tractor powered by a 30 HP engine that can do the basic work of a tractor including lifting soil on the surface so that oxygen will fill up the soil and the mineral can reach the root of the plant life on it and kill the unfavorable weeds in the process. The article will discuss all functional elements of the tractor and necessary specifications from design, manufacturing, and final assembly. Further publications will involve optimal design and construction to head for the final products of its commercial endeavor.

Corresponding Author:

Iwan Harianton
Department of Manufacturing Engineering, Faculty of Manufacturing Engineering Technology
Bandung Polytechnic of Manufacturing
Kanayakan Street No. 21 Dago, Coblong, Bandung 40135, Indonesia
Email: iwan_harianton@yahoo.com

1. INTRODUCTION

The population of more than 270 million people in the country situated at the equator had fulfilled its food source requirement once in 1994, but before and after that the country is not imported food supplies blocking the national spending up to as high as 7.9%, while the agriculture soil open up for around 19.6 million acres [1] with only low productivity gain. The farming technology operated by the traditional farmer is only up-to-hand tractors operated by the operator or the farmer himself. Large companies working in agriculture are mostly planted palm three to produce crude palm oil that demanded by numerous industries such as cooking oil, margarine, soap, and other fat products. Meanwhile, the main food resource for common

Indonesian people is rice, which rarely touches by companies alike. The reason is due to low added value generation from rice while the country could not hinder such price drop during the harvest period. On the other hand, importing rice is even more likable by companies because the price is higher and the imported rice is provided for higher economic trading places such as the shopping center or large shopping malls for those who call they have.

The main problem that this paper address is based on the early information from the practitioners Satrindo Mitra Utama, Ltd., in its blogger that the demand for 4-wheeled medium tractors with 40-50 HP engines has been climbing up before the pandemic with the demand for around 2,000–2,500 unit per year [2]. While the producers and importers can only supply of above demand of 1,200 units per year due to some regulations on the local content of the agricultural machinery market in the country. From the sale statistic, 92.5% are sold to large companies that operate larger soil for more than 500 acres each. While about 90 units on average in the last 5 years were sold to individual farmers who operate farming soil of fewer than 10 acres. The other problem of the common rice farmers is also the buying power of the farmers themselves who are mostly less than the capital required to have medium tractors. So, some financial arrangements may be required to accelerate the productivity increase of Indonesian soil.

The challenge of the higher education intervention on medium tractor development will be not only to outreach the local content of the machine but also to offer the lowest possible cost of the tractors or at least some financial arrangement could be searched for a government subsidy or some kind of community arrangement that farmers be able to own the machines based on the lowest possible monthly payment or paid after series of the harvest period. The researcher approached the local chamber of commerce received by the deputy director for business based on applied technology, he mentioned that the technology is certainly will help farmers to increase their soil productivity but consider that the operator may not be available due to the massive economic attraction of the city. So that the tractor should be equipped with the unmanned global position system control so that the tractor can operate by itself with proper assignment of the area in which its soil should be prepared for the coming rice plantation.

This paper is addressing the intervention of vocational higher education in the design and manufacturing of low-cost tractors that could be produced powered by a 30 HP engine or stronger that could perform work and run on the rural road at 40 km/hour. The design of the tractor will include the overall design such as length, width, height, weight, and the ground clearance of the tractor, detailing in the design of the dashboard of the cockpit, and operator chair analyzed under ergonomic analysis [3] so that it can be adjusted as the operator height and weight that he driver work pleasurably pleasant if any, display control on board, engine frame, body, chassis, engine later be prepared internally, global positioning system (GPS) based control system, while other standard parts such as steering system, gear reducer, drive system, and brake system will be managed under the supply chain management.

2. RESEARCH METHOD

The tractor is already being used by farmers since the early 20th century, the oldest literature has shown tractors as early 1902 operated by migration west in virgin land using a steam-powered model [4]. The development is very rapid, as the land in the United States (US) is huge and the immigrant increasing tremendously so that the source of food increase very rapidly too. In the US farmer history alone tractor has been operated under a series of fabrication starting from 1908 a tractor called Hart-Parr 30-60, 1909 found the serial of Avery farm city, 1913 Bull tractor, 1914 Wallis Cub, 1914 Moline Universal, 1916 Nilson, 1916 Square Turn, 1917 Fordson F., 1921 International Harvester (IHC) 15-30, 1924 IHC farm all, 1924 Allis Chalmers U., and 1939 the famous Ford 9 N. Ford Motor Co.'s tractor arm had already pushed the industry with its model F and its unprecedentedly low price in the 1920s. In 1939 they returned with the novel "three-point hitch", as well as adopted the major industry advancements from the previous two decades.

The research had tremendously hamper by information that to fulfill the huge demand for food, the country needs more productive tools such as tractors. So there is no more to return that big population like here in Indonesia, the availability of the tractor is mandatory. Certainly, the design and construction of the tractor are already mature to some extent, the only advanced research would be on the control system, maneuverability, and the energy sources that are renewable or using green energy.

The proposed solution where the technology had been mature, so the research will start with design engineering, followed by process engineering, and conclude with production system engineering. Design engineering will involve the design of the global look that will bring branding of the product in the long run. In this article, the design will show 3-variants that will detail only in the first version as it will be launched for the first commercial action. The second design and the third design will not be detailed, but certainly, they carry their branding strategy as they differ in power and maneuverability as well as the control system. The first version displayed in this article will be the basic control system provided by the lowest entire tractor products series that Bandung Polytechnic of Manufacturing (Polman Bandung) will focus on. However, the general basic design of the tractor will be similar as it displayed in Figure 1. The terms involving the tractor design will be carried out throughout the development of the tractor. The variation will include the internet of things (IoT) technology under the GPS control system as a new approach.

2.1. Design engineering

The design of the tractor can be represented as displayed in Figure 1. The notation in Figure 1 will reflect our basic force calculation and geometrical configuration of the tractor and its virtual pivot points of the apparatus attached to the tractor. W_I is the pivot point of the attachment, while W_T is the center of gravity of the tractor. The design is plotted inclined to ease the perspective of the inclined angle θ and the direction of the force α. Then, the basic calculation will follow (1), (2), and (3) for all design configurations.

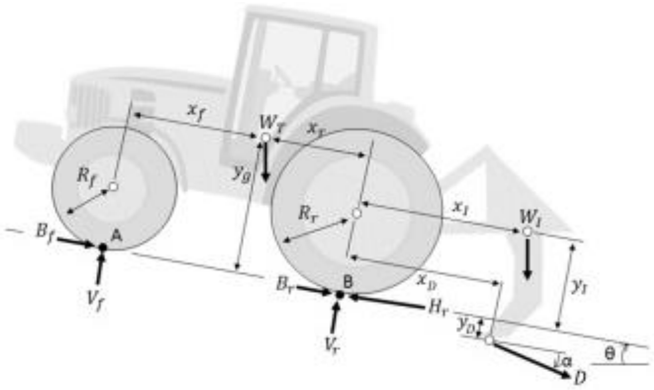


Figure 1. The basic design of the tractor as published in Massachusetts institute of technology (MIT) open-access articles [3]

The sum of the vertical force on both front wheels is (1),

$$V_f = \frac{1}{x_f + x_r}(W_T(x_r \cos(\theta) - y_g \sin(\theta)) + D(y_D + \cos(\alpha) - x_D \sin(\alpha)) \\ + W_I(- x_I \cos(\theta) - y_l \sin(\theta))) \quad (1)$$

and the sum of the vertical force on both rear wheels is (2).

$$V_r = \frac{1}{x_f + x_r}(W_T(x_r \cos(\theta) + y_g \sin(\theta)) + D(-y_D + \cos(\alpha) + x_D \sin(\alpha)) \\ + W_I\left((x_I + x_r + x_f)\cos(\theta) + y_I sin(\theta))\right) \quad (2)$$

It is assumed in the conventional tractor configuration that only the rear wheels are driven. To move the tractor forward at a constant speed, the rear tires must provide the net horizontal force:

$$H = B_f + B_r + D_{cos}(a) + (W_T + W_I)\sin(\theta) \quad (3)$$

The calculation of the actual wheel torque necessary to achieve H_r and the calculation of resistance forces B_f and B_r, requires an analysis as described in section 3.3 of the article [4]. The forces will be used to select the appropriate tire that could withstand the soil type and the resistance. Fortunately, the tire had been innovated by the tire producer that we could pick the operation as the resistance required.

The tire-soil model is summarized here as described by Wong [5] and is commonly accepted in terramechanics. Research groups have suggested accuracy improvement which sometimes comes at the cost of experimental data. Senatore [6] has provided a good summary of potential improvements to the tire-soil model.

In agricultural soils, the pressure required to penetrate the ground increases with depth. Soil pressure as a function of depth is commonly expressed in terramechanics using Bekker's or Reece's as follows [7]:

$$p = (ck_c^j + w\gamma_s k_\emptyset^j)(\frac{z}{w})^n \quad (4)$$

where, p = soil pressure, c = soil cohesion, k_c^j = cohesion constant, w = tire width, γ_s = soil bulk density, $k_\emptyset^j$ = friction constant, z = depth below the soil surface, n = depth exponent (an experimental value relating penetration depth to penetration resistance).

$$s = (c + p_{tan}(\emptyset))\left(1 - e^{j(i)/k}\right) \quad (5)$$

where, s = soil shear strength, p = soil (normal) pressure, c = soil cohesion, φ = soil friction angle, k = shear modulus, j = shear deformation, i = slip at interface.

The net vertical force may then be mathematically expressed as (6).

$$V = wR\int_{\theta_c}^{\theta_f}[p(\theta)\cos(\theta) + s(theta, i)\sin(tehta)]d\theta + w2RP_l\sin(\theta)$$
$$+wR\int_{\theta_c}^{\theta_r}[p(\theta)\cos(\theta) - s(\theta, i)\sin(\theta)]d\theta] \quad (6)$$

The horizontal force will be expressed as (7).

$$H = wR\int_{\theta_c}^{\theta_f}[-p(z)\sin(\theta) + s(theta, i)\cos(theta)]d\theta + w\int_{O}^{L(\theta_c,R)} s(\theta)dx$$
$$+wR\int_{\theta_c}^{\theta_r}[p(\theta)\sin(\theta) + s(\theta, i)\cos(\theta)]d\theta \quad (7)$$

For both equations variables are defined as H = drawbar pull, V = vertical ground reaction, w = tire width, R = tire radius, P_t = net tire pressure. The angles θ_c, θ_f, and θ_r define the tire shape and sinkage into the soil as shown in Figure 2.

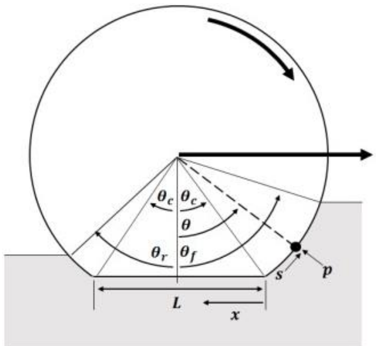


Figure 2. Parameters of tire parameter for calculation of forces at the interface

2.2. Process engineering

In the manufacturing process, there is no new thing that involves in tractor production. All components were fabricated in the workshop without significant obstacles. The only concern is to eliminate waste as its transforms from prototype production to serial production. So the focus activities in the research are to plan the process and identify waste that may occur in the part-making. The wastes were identified under 7+1 wastes including overproduction, waiting time, process, inventory, motion, reject/rework, transportation, and underutilized human talent [8].

Overproduction will be eliminated under the policy that only produce tractor when the buyer already put in the order. So the only work to do is to speed up the production process to reach customer demand. The current setup is to deliver the product within one week, when the customer expects sooner, then the strategy of production may be adjusted such as assembly to order (ATO) and test to order (TTO).

Waiting time: there are three possible waiting times, namely: i) waiting for material to come, ii) waiting for the previous process to finish, and iii) waiting for the machine to be maintained. The first waiting could be eliminated by the just-in-time (JIT) concept or to make sure the supply chain work accordingly. The second wait is to plan the cycle time that has been used to complete the work, parallel work is the solution to the late process. The third wait can be eliminated by implementing total productive maintenance (TPM) or reliability-centered maintenance (RCM) that involves the operator doing autonomous maintenance and monitoring the condition of the machine by filling up the “red tag card” when an abnormality occurred.

Process: waste involving added value waste and non-added value waste. Added value waste happens when the operator use under optimal tools speed. While the non-added value waste occurs in the process due to lack of the skill of the operator, enhancing the skill to set up, skill to measure, skill to adjust apparatus, skill to optimize the speed will be the solution.

Inventory: this can be in the form of incoming inventory and in-process inventory both are caused by poor planning and integration of the supply chain so that just in time scheme should be governed within the process of implementation and improvement. Motion: the act and move of non-adding value in the operation. Eliminating a move that adds no value to the product is a must and it can only be done when the operator is aware of such waste completely. Reject/rework: certainly reject or rework is the situation where all loss occurred usually happens when some specific tolerance is inserted in the part requirement; therefore, plan the operation so that the critical specification had been anticipated perfectly.

Transportation: it is a non-added value act, it requires work, tools, and human hours but no added value at all. So, the production system engineering has to work to minimize transportation. Underutilized human talent: means that ideas for improvement and better solutions to problems will come from the people and nothing else, therefore people should be invited to contribute his/her ideas to solve problems or improve the operation that is currently practiced.

2.3. Production system engineering

The research involves the study of the motion of the material, people, and information. The output of this research will be how big the area of the production is, how the components are being fed, how the components are being carried to the assembly line, and how the operator or robot can assemble the parts accordingly. The layout and the aisle and transport equipment being carried in the production line are part of the main output of this engineering research. The tractor is a kind of product that is produced in a huge number of the unit within a given time. The general rule of production system engineering is to fulfill the demand of the consumers by arranging production time as called “*takt time*” or “*cycle time*”. So, all involved processes and assembly should be done within the *cycle time*. Any process or assy requires more than its *cycle time* should be done in parallel work. Waste in the production system is mainly inventory and transportation, inventory waste is due to the poor arrangement of the supply chain and poor planning, while transportation should be minimized under the layout design and the process of minimal routing.

The research started from the capacity of the production line in response to its estimated market demand, the above study that the Indonesian market the medium tractor was about 2,000–2,500 units in 2019, and a little decline during the pandemic, but it is expected to normal in the year 2022 due to tight financial policy related to a commodity that the country could offer. Rice and other crop production are among the traditional products that need to be developed and solved. Because theoretically 19.6 million acres of agricultural soil could produce 4 million tons of rice, 4 million tons of soybean, 3 million tons of corn, and other food supplies sufficiently, Indonesia is still a net importing country of food supply in this region.

3. RESULTS AND DISCUSSION

The design and manufacturing medium size tractors is a very strategic decision due to the situation of the farmers who are just at the beginning of opening their capacity to fulfill the increasing demand due to population increase and urbanization take place in the current challenge. So more modern technology in the farming industry is expected but the economic power of the farmers is presumably lower to date. Therefore, the government urges vocational higher education such as Polman Bandung to take part in this interface to stimulate the development of the farming business. The results of this research and development of the tractor had been divided into three engineering activities, namely design engineering, process engineering, and production system engineering as suggested by Kalpakjian *et al.* [9].

3.1. Design engineering

The first model had been innovated to cope with the soil work with the lowest version of the bearing, the characteristic is simple, functional, and affordable. The sketch design is illustrated in Figure 3, we called this model “Polagrik” meaning that this tractor is made by Polman Bandung for the agriculture variant small. The engine is located in front of the driver, directly connected with the rear wheel drive under the 3-speed transmission to reach 40 km per hour on a rural road. One seater operator adjusted to meet the driver's comfort and all cockpit sufficient enough for controlling the maneuver of the tractor [10]. Its design specification is illustrated in Table 1.

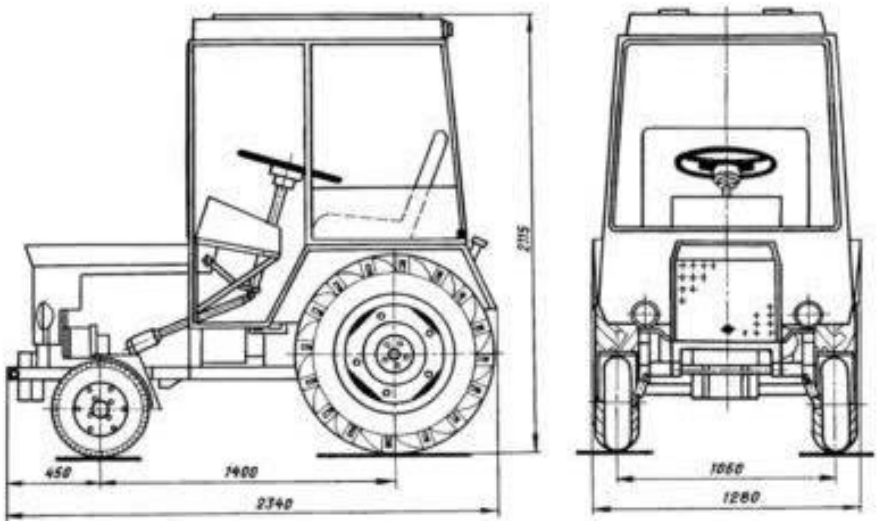


Figure 3. Polagrik medium multipurpose tractor 30 HP

Table 1. The design specification is illustrated

Specification		Details
Dimension	Length	3,296 mm
	Width	1,551 mm
	Heigh	2,382 mm
	Distance center	2,387 mm
	Step up	289 mm
Weight		1,490 kg
Chasis	Hollow profile	60×60 mm
Engine	Kubota diesel	30 HP
Gear Box and Clutch Kubota F2000		Performance V8 SXS 4×4 Buggy Engine
Driver sytem		Youbiseng (Fujian) Machinery Industrial VA 34226-296
Front Tyre		Overall dia. 25 inches, Tutric K301 10.0/75-15.3 (TRA I-3)
Front Rim		Overall dia. 17 inches, PRONAR 13.00×17
Front Suspension		EUCLID E-4677A
Rear Tyre		Overall dia. 45 inches, Tutric Paddle 9.5-24 (TRA: PR-1)
Rear Rim		Overall dia. 30 inches, PRONAR DW20L
Rear Suspension		Allis Chalmers AC-219D
Samwo Cabin		DAEDONG TG (PX1300ATSC)

The specification above has been innovative to handle the medium challenge of the wet soil suitable for rice plantation. It has features that most fertile soil can be flipped up for oxygen turn around and also making minerals close to the rice root. This tractor is also equipped with an attachment interface under the standard connection that makes it easy for the operator to carry around 1 ton of the attachment for processing reach soil even in an inclined surface less than 20 degrees, more than that will not be recommended because this tractor is light enough to flop over when the inclination above 30 degrees. The final design has been publicly exposed as it is seen in Figure 4. The new feature that is introduced is the GPS Control system under IoT technology.

Figure 4. The final design of polagrik multipurpose tractor 30 HP

3.2. Process engineering

The process of engineering starts with the list of the components that are purchased and the components that are manufactured in-house. Purchases components including nuts and bolts, tire, gear reducer, engine, gear transmission, drive system, brake system, steering system, and panel-panel gauges for engine and maneuver system control. The components that are manufactured in the house include the chassis, engine cover, body, roof panel, fuel tank, and dashboard of the driver. The integration of the standard components such as the bracket, mounting part, and interface have been manufactured internally. Among the work that had been done internally can be seen in Table 2.

Table 2. The elements of the tractor are fabricated internally using the Polman facility and the time taken

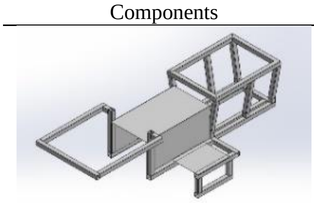
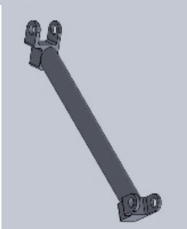
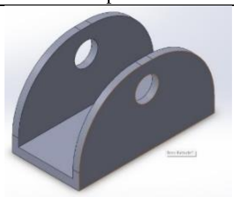
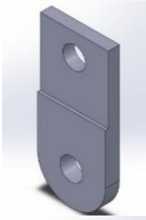
Components	Material	Process routing	Time (minutes)
	SC45 square pipe 60×60 mm	Cutting Welding Painting	75 60 90
	SPKNL	Cutting Turning Broaching Assembling Painting	50 100 56 46 90
	SC45	Cutting Turning Broaching Painting	60 90 60 90
	Steel alloy	Cutting Milling Drilling Taping Honing Balancing	60 320 50 50 120 100

Table 2. The elements of the tractor are fabricated internally using the Polman facility and the time taken *(Continued)*

Components	Material	Process routing	Time (minutes)
	SC45	Cutting Milling Drilling Welding Painting	60 100 30 35 60
	SC45	Cutting Milling Drilling Painting	60 80 50 60
	3 mm steel sheet	Laser cutting Bending Drilling Welding Painting	120 60 60 120 100

3.3. Production system engineering

The final manufacturing operation will be the assembly of the tractor, there are 5-stages of sub-assembly of the tractor, and each stage requires 32 hours for students' exercise. It could be shortened as short as 8 hours when professional labor work on it. So the production capacity can be about 45 units per year up to 180 units per year depending on the market demand. Figure 5 illustrates the assembly process of the tractor.

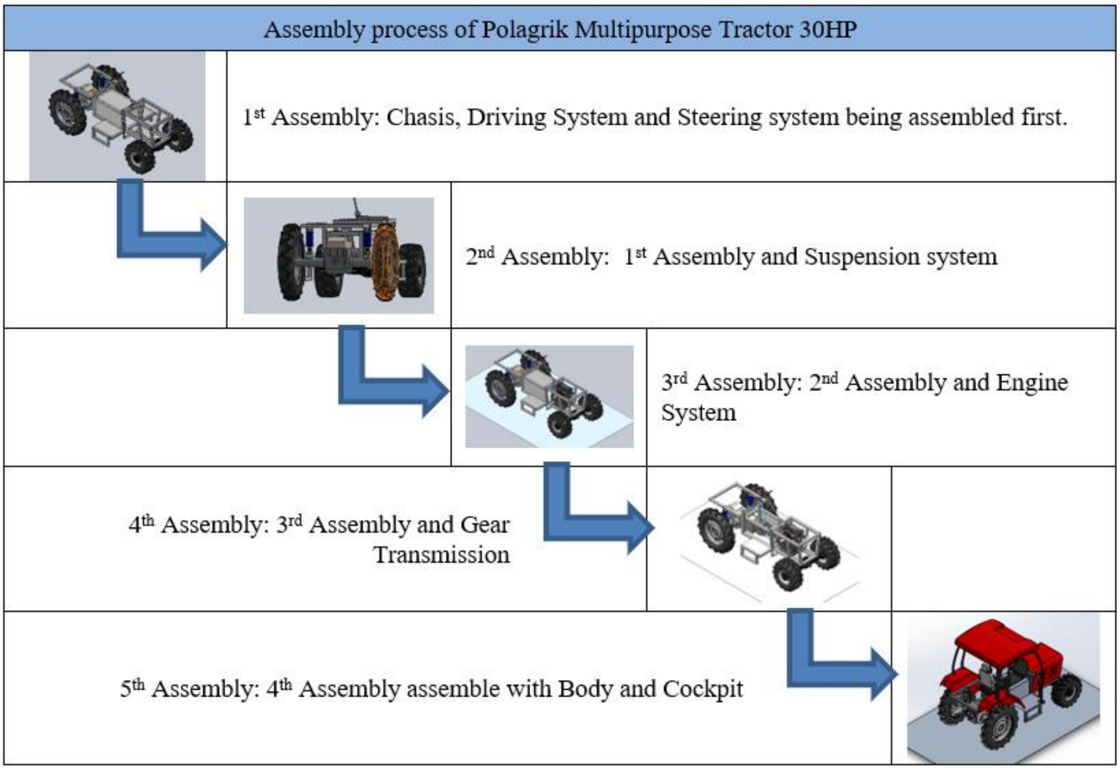


Figure 5. Assembly of the polagrik multipurpose tractor 30 HP

The assembly process had been prepared in an assembly plant that will make the work possible to be completed within its takt time. The area should cover the supply components in each assembly station and make the assembler feel comfortable putting one component after another. The takt time is defined by the availability in a year divided by the total tractor demand in the same year [11]–[13].

$$Takt\ Time = \frac{\text{Total availability}}{\text{Total tractor demand}} \tag{8}$$

The demand in the 1st year will be 45 units, while the maximum supply is predicted to be 180 units per year in the 5th year. Therefore, the 1st year takt time will be 32 hr/week × 45 weeks/year divided by 45 units so that the 1st year takt time will be 32 hours. In the 5th year when the demand will be expected to increase to 180 units, the 5th year takt time will be 32 hr/week × 45 weeks/year divided by 180 units equal to 8.0 hours. Certainly, some adjustments should be done every year, as the demand is expected to increase every year. The basic thinking of time reduction will be to equip each sub-assembly station with more automated tools, several assemblers, and a handling system so that the station should be able to complete its task within the given takt time [14]–[16]. Figure 6 illustrates the sub-assembly station along with respective operators in each assembly station subject to improvement every year until it could finish each task in only 8 hours in the fifth year of operation [17]–[20].

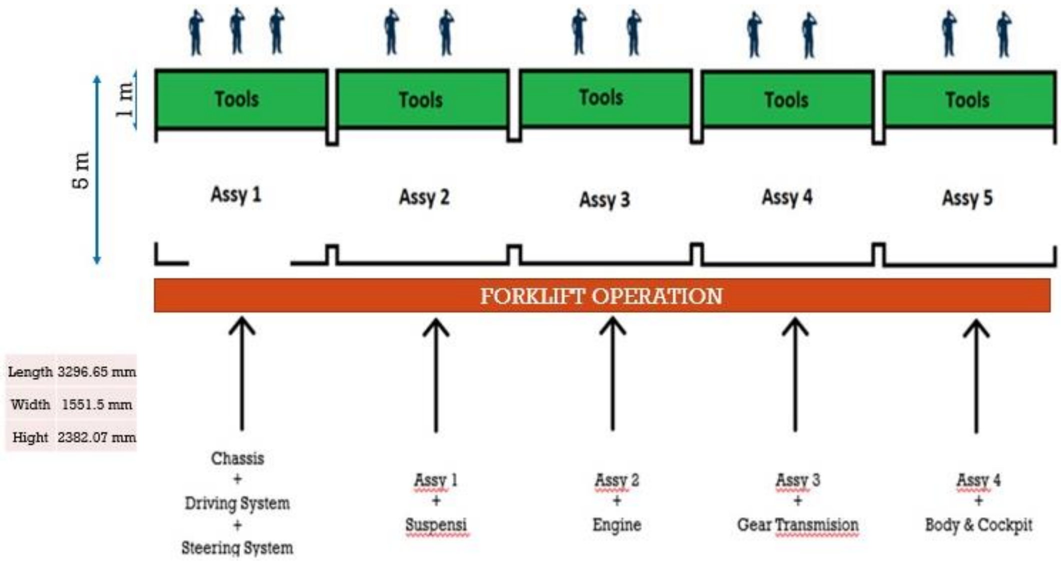


Figure 6. Assembly line workstations subject to improvement

4. CONCLUSION

Detail design engineering will do some software analysis on the forces exerted statically and dynamically on the wet soil field. The further study aims to evaluate the components that directly work under force influence. Some ergonomic analysis had been done to bring the operator's cockpit a place for a better working environment. Process engineering provides the manufacturing data, processing time, and routing so that each part is done before coming into sub-assembly. The analysis of waste elimination is very important for the basis of time improvement, while the quality should be met as the profession is certified in today's practices.

Production system engineering delivers the final assembly operation along with the necessary setup of the assembly stations and the sub-assembly being fed to the station. Waste analysis on transportation and inventory both incoming and in-process inventory are critically important to achieving a lean production line. More importantly, the production system engineering will supply the necessary products on time based on the demand and the request from the customers. This research will continue in the next series of publications concerning the other two other tractor variants that had been developed internally to solve Indonesia's shortage of food supply using providing more productive technology on hand. However, as the economic level of the farmers is still below the requirement of this technology, then massive involvement of vocational education and higher vocational education should be maintained for the lowest possible cost of the tractors.

ACKNOWLEDGEMENTS

Authors thank Polman Bandung and Chamber of Commerce of West Java, both allow researchers to continue digging up the possibility of producing tractors from 30 HP to 50 Hp or above for the West Java farmers. The research funding will be shared between the Ministry of Education and research CQ. Directorate General of Vocational Education and Director Academic Diksi who allow us to continue building tractors as the students exercise in the teaching factory.

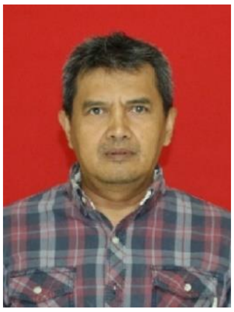
REFERENCES

[1] Center for Soil and Agro-climate Research and Development, *National seminar on technological innovation on soil and climate data sources (in Indonesian)*. Bogor: Pusat Penelitian dan Pengembangan Tanah dan Agroklimat, 2005.
[2] Satrindo Mitra Utama Ltd., “The authorized dealer in Indonesia for agroforestry and construction equipment,” 2019. https://satrindo.com.
[3] Y. Li, Q. Cao, and F. Liu, “Design of control system for driverless tractor,” *MATEC Web Conf.*, vol. 309, pp. 1–12, Mar. 2020, doi: 10.1051/matecconf/202030904001.
[4] G. F. Díaz Lankenau and A. G. Winter, “An engineering review of the farm tractor’s evolution to a dominant design,” in *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Aug. 2018, pp. 1–19, doi: 10.1115/DETC2018-86285.
[5] J. Y. Wong, *Terramechanics and off-road vehicle engineering: terrain behaviour, off-road vehicle performance and design*, 2nd ed. Oxford: Butterworth-Heinemann, 2009.
[6] C. Senatore, “Prediction of mobility, handling, and tractive efficiency of wheeled off-road vehicles,” Virginia Polytechnic Institute and State University, 2010.
[7] J. K. Liker, *The Toyota way: 14 management principles from the best manufacturing company in the world*. Jakarta: Erlangga Publishing Co, 2006.
[8] O. L. Kolekar and J. M. Potekar, “Ergonomic improvement in operator seat and controls of small tractor,” *Int. J. Res. Eng. Technol.*, vol. 3, no. 5, pp. 389–396, May 2014, doi: 10.15623/ijret.2014.0305071.
[9] S. Kalpakjian, S. R. Schmid, and H. Musa, *Manufacturing engineering and technology*, 6th ed. Singapore: PrenticeHall, 2009.
[10] G. L. Curry and R. M. Feldman, *Manufacturing systems modeling and analysis*. Berlin, Heidelberg: Springer, 2011.
[11] H. Meyer, F. Fuchs, and K. Thiel, *Manufacturing execution systems optimal design, planning, and deployment*. New York: McGraw Hill Professional, 2009.
[12] Y. Monden, *Toyota production system: An integrated approach to just-in-time*, 3rd ed. Boca Raton: CRC Press, 1993.
[13] J. P. Womack and D. T. Jones, *Lean thinking: Banish waste and create wealth in your corporation*. New York: Free Press, 2003.
[14] J. K. Liker, *Toyota way: 14 management principles from the world’s greatest manufacturer*. New York: McGraw-Hill Education, 2004.
[15] A. Gola, “Design and management of manufacturing systems,” *Appl. Sci.*, vol. 11, no. 5, pp. 1–3, Mar. 2021, doi: 10.3390/app11052216.
[16] W. E. Deming, *Total quality management*. Jakarta: Rineka Cipta, 2005.
[17] J. Juran, *Total quality management*. Jakarta: Rineka Cipta.
[18] R. B. Chase, N. J. Aquilano, and F. R. Jacobs, *Operations management for competitive advantage*, 9th ed. Boston: McGraw-Hill Irwin, 2001.
[19] J. Matuszek, T. Seneta, and A. Moczała, “Assessment of the design for manufacturabilityusing fuzzy logic,” *Appl. Sci.*, vol. 10, no. 11, p. 3935, Jun. 2020, doi: 10.3390/app10113935.
[20] M. Relich and A. Świć, “Parametric estimation and constraint programming-based planning and simulation of production cost of a new product,” *Appl. Sci.*, vol. 10, no. 18, p. 6330, Sep. 2020, doi: 10.3390/app10186330.

BIOGRAPHIES OF AUTHORS

Iwan Harianton is an experienced associate professor with a demonstrated history of working in the Manufacturing Engineering Department. Skilled in Manufacturing Technology and Manufacturing Systems as well as Entrepreneurship of a Bachelor's degree course under an applied research institute, Bandung Polytechnic for Manufacturing. His primary research is in Internal Combustion Engines for fisheries in Sidoarjo, Developing the Double Power Ecological Engine with Spark Assisted in Lean Mixture, and still going on the Development of a Range Extender for an Electric Vehicle for the mobility battery charger. His true passion is to be lectured on modern manufacturing systems and engineering that involve more than 2,000 students of Diploma and Bachelor Levels. The basic understanding for the students is that producing a motorcycle in less than 6 seconds, an SUV Car in less than 85 seconds, and an Aeroplane of 300 seaters in less than 24 hours, are unbelievably proven cases. He can be contacted at email: iwan_harianton@yahoo.com.

Agus Surjana Saefudin is a senior lecturer and practitioner in Tools and Die Making, Material science of polymers, tooling design, and analysis at the Bandung Manufacturing Polytechnic (POLMAN Bandung). His expertise is in designing and manufacturing special machines for medical devices such as leak testers and endurance test machines and clamps for circumcision products. Other expertise is in tooling for press tools, jigs, and fixtures and molding for automotive components. Currently, he has an interest in designing and developing agricultural tools and technology. He can be contacted at email: agus.surjana.s@gmail.com.



Mohammad Ali Suparman is an experienced senior lecturer with a demonstrated history of working in Production Tools and Dies, and General machinery, later his interest more in the electronic control system by presenting research on the Development of manufacturing automation systems of complex multi-component production known as Flexible Manufacturing Cell. Also, he did more computer programming to develop an integrated postprocessor for milling operation, turning, and drilling using SolodCam 2010 Software, and finally developed a 5-axis CNC Moriseiki NMV5000 DCG. His current research is in the development of wireless control system based on a global position system or local position system using reading the reference point to coupe with the areas to be mapped and monitor. He can be contacted at email: ali_suparman@polman-bandung.ac.id.