Research Article

Avoiding Covid-19 Using a 3D Digital Mock Up and Augmented Reality with Cobot in Digital Factory

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Abstract
The Fourth Industrial Revolution or Industry 4.0 is extremely relevant and important in manufacturing for several reasons. Failing to adopt the technology of the Fourth Industrial Revolution can cause organizations to fall behind, as their operations are not digitized enough in benchmarking competitors. A major industry as bicycle manufacturing needs to be transformed into a digital factory in order to keep up with the evolving technology. The objectives of this research are in designing a 3D digital mock up and Augmented Reality (AR) for bicycle frame production in the form of digital factory for increasing production capability by decreasing the break-even point whilst avoiding Covid-19 contraction using Tecnomatix Plant Simulation and Unity 3D programs. This research constructed three alternative digital factory layouts that are designed by using a 3D simulation program. The risk of Covid-19 contraction points and the three layouts of cost per unit are analyzed. The results show that the break-even point of the first to the third layouts with Automated Guided Vehicle (AGV) are 26,580, 26,322 and 25,354 units respectively. The result of the risk about Covid-19 contraction points from the first to the third layout with AGV are 21,272, 2,872 and 0 points respectively. This means the most appropriate layout for bicycle frame production is the third layout due to the best break-even point that can significantly avoid Covid-19 contraction. The benefit of this research is to integrate a 3D digital mock up, AR and Cobot including AGV to assist the resilience of operations with a dynamic industrial environment.

Keywords: Covid-19, 3D digital mock up, Augmented Reality (AR), Digital factory, AGV, Cobot

1 Introduction

Referring to the World Health Organization (2020)'s report, the number of patients with confirmed cases is over 5 million with over 300,000 deaths worldwide and the number of Covid-19 patients is still rising. A number of countries have set pandemic counter measures for the effort to prevent pandemics such as lockdowns, quarantines, and social distancing [1]. Moreover, the WHO has launched advice on preventing the further spread of Covid-19 such as basic hand hygiene measures, frequent hand washing, the use of alcohol-based hand sanitizers, and the use of face masks [2]. Yet, some countries disregard the WHO's advice resulting in a severe pandemic [3]. However, in accordance with the Royal Thai Government's report, Thailand has been praised for stringent measures to control the spread effectively from foreign media due to the Government's rigid policies. There are, for example, the Royal Thai Government has issued a National Emergency Decree effective on 26th March 2020 that recommended about maintaining a distance of at least 1.5 m from all other persons at all times, washing hands frequently or using an alcohol-based hand sanitizer, and using a face mask, etc. Then, the Government has announced a nationwide curfew beginning in April 2020 and again in July 2021. Furthermore, the Government implements a 14-day state quarantine measure for persons that travel to Thailand from abroad.

However, there isa gap still exists as in 2021 with Delta Corona Virus Variant, many factories found Covid-19 cases rising and caused them to shut down their operations immediately. There is a need to suggest how to avoid Covid-19 by implementing social distancing in the factory. Therefore, the objectives of this research are to design a 3D Digital Mock Up and Augmented Reality in a digital factory for avoiding Covid-19, by using Tecnomatix Plant Simulation and Unity 3D programs. The alternative of factory layouts in a digital factory can be evaluated in conjunction with economic analysis.

Nowadays, traditional manufacturing plants are being replaced by digital factories, which have more efficiency and productivity. This research aims to design a new digital factory (DF) for the bicycle production from the original factory layout by using a 3D digital mock up and Augmented Reality (AR, and to consider the economic and the risk of Covid-19 contraction in the production area.

2 Materials and Methods

Almost all production today can assess productivity and improve safety through modeling. For example, the verification of movement between operator and machine, especially for highly hazardous applications, such as vertical centrifugal casting, which is a process of pouring the molten metal into a rotating mold for casting [4]. Alternatively, the model may be used in environmental conservation, for example, to develop a decision support framework to quantitatively assess risks in various environmentally-friendly transports. [5].

This section describes the advantage of software implementation in digital factory design, including simulation software and AR technology, that can make visualization of the process flow and potential defects in the manufacturing process. Therefore, the simulation software is appropriate to design the digital factory, which is described in detailed as follows.

2.1 *Digital factory in simulation software*

The fourth industrial revolution is characterized by the increasing usage of digital tools, allowing for the virtual representation of a real production environment at different levels, from the entire production plant to a single machine or a specific process or operation. In this framework, digital factory technologies, based on the employment of digital modeling and simulation tools, can be used for short-term and medium-term analysis including validation of the production system [6].

The digital factory (DF) applies a virtual environment for designing of manufacturing processes using simulation and virtual/augmented reality technologies to optimize design, layout, productivity, cost and other factory activities [7]. In digital factory environments, digital models and information are visualized and simulated with resource constraints. This allows users to design, analyze and predict the behavior of production systems using simulation software. There are factors that need to be analyzed in a process flow, for example, product design modeling and simulation, process and production planning, process validation, the layout of a factory in relation to production process, scheduling and control, and also control with monitoring of automated production systems. The implementation of a digital factory can result directly in economic benefits as well as process improvement. In addition, normally production equipment is often inflexible with the best possible factory layout. Cost savings in the design phase can reduce a major amount of cost reduction in the production phase. Some advantages are, for example, product/process verification can be performed before starting of production, optimization of the process can be compared in a variety of complex ways, bottlenecks and collisions in the process can be avoided, ergonomics and safety analysis can also be done in 3D virtual environment [8], etc.

The advantage is that it is possible to perform simulations and reconfigure models to evaluate, modify or compare alternative scenarios to achieve demands of increasingly competitive markets [9].

In some cases, a discrete system simulation model has been proposed for efficient management of inventory and improvement of the productivity of production shop through rearrangement of production layout. The Technomatrix simulation software has been used to develop the simulation model. Therefore, the proposed methodology adopts it to improve the process performance of the discrete system production processes without physically changing the actual production process [10].

2.2 *3D digital mock up with AR and Cobot*

At the digital level, 3D motion simulation is mainly applied for layout and material handling system design, by using kinematics modeling and collision detection. The input data for setting up the model are represented by the initial manufacturing cell layout, 3D models of the manufacturing cell equipment, 3D robot models with kinematics and digital human models to simulate the human operators. Based upon these data, 3D motion simulation allows to determine the optimal manufacturing cell layout and dimensions as well as to identify collision-free robot paths [6].

The 3D digital mock up and Augmented Reality (AR) create objects in a 3D environment from the developing, visualizing, testing which can result in shorter development time. The usage of AR and Cobot (Collaborative robot with human) in simulating a digital factory can aid in the decision-making and efficient operation of a manufacturing facility [11]. In particular, at visualizing, the design and operation can reveal some shortages in the design of process and initiate changes or eliminate errors whilst effectiveness can be increased. The design of shop floors in 3D layouts can also be visualized in simulation software where layouts can be compared within complex manufacturing requirements. Moreover, material flow and interaction with humans and machines can be simulated and tested according to the safety standards [7].

2.3 *Methodology*

2.3.1 Procedures and research methods

The procedure of research methods begins with studying the related research, theories and studying the Tecnomatix Plant Simulation application. Then, the necessary information as input values are gathered for using in the simulation software. After that, the production layouts are designed aiming to increase the production capability and to avoid the risk point of Covid-19 contraction.

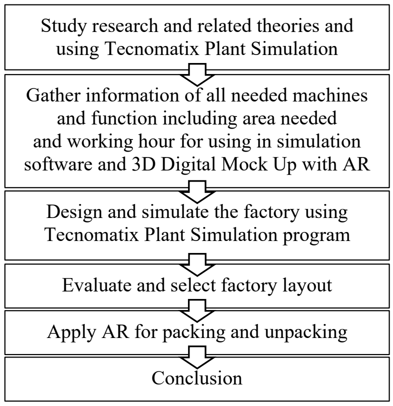


Figure 1: Research methods.

After production layout simulation results are calculated, the layouts are compared for appropriate selection. Additionally, the AR is applied for simulating packing and unpacking products. The results are concluded as the final step of the research implementation (Figure 1).

2.3.2 Machine data in the production process of DF

This section is to gather information on the necessary machines in DF. The information includes type of machine, duty, quantity as illustrated in Table 1, and the working area of each machine is illustrated in Table 2. This information is required for the plant layout design program. Then, the new production process is define by using the digital factory's machine according to the production orders.

Table 1: List of the necessary machines in the digital factory

No.	Machine	Duty	Quantity
1	Robot pick and place	Pick and place workpieces	12
2	Automated Guided Vehicle	Transport the product automatically	3
3	Fiber Laser Cutting	Cut the steel to the required size	8
4	Conveyer	Conveying material on the belt	44
5	Forklift	Conveying materials that received from trucks	1
6	Paint Dryer Machine	Drying the paint	2
7	Painting Machine	Paint bicycle	2
8	Packing Station	Automatic packing	2
9	Rack Rane AS/RS	Store the products automatically	100

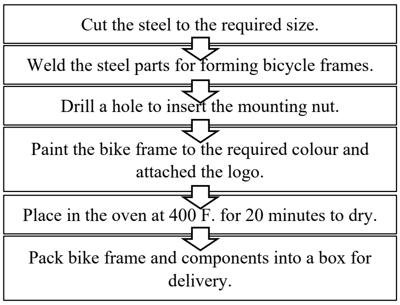


Figure 2: The main process of bicycle frame manufacturing.

Table 2: The working area of each machine

Machine	Area		
	Wide (m)	Length (m)	Area (sq-m)
Robot pick and place	1	1	1
Automated Guided Vehicle	0.8	1.2	0.96
Fiber Laser Cutting	1.2	3	3.6
Conveyer	1	-	-
Forklift	1	2.4	2.4
Paint Dryer Machine	2	3.5	7
Painting Machine	2	3.5	7
Packing Station	2	3.5	7
Rack Rane AS/RS	3.5	10	35

The main process of bicycle frame manufacturing is defined in steps as shown in Figure 2.

2.3.3 Other components of the production process

The digital factory machines from Table 1 are arranged according to the production process (Figure 2). The equipment and station in the production layout are added in the simulation software as a check point for each production process, including ;

1) Source (steel from trucks)
2) Robot arm handle
3) Steel cutting machine
4) Staff room
5) Welding machine
6) Paint sprayer
7) Pack things into boxes.
8) Warehouse

2.3.4 Study of the working hours

The standard time is used to calculate the productivity and to investigate the bottleneck in the production process, which can be analysed in the simulation software. Then, the standard time of each process is presented in Table 3.

Table 3: Bicycle frame standard time in the process

Frame Manufacturing Time		
Machine	Time (min/EA)	Total Time
Raw steel release time	1.45	
Cutting 1	1.30	
Cutting 2	1.30	
Cutting 3	1.30	
Cutting 4	1.30	
Cutting 5	1.30	
Cutting 6	1.30	
Cutting 7	1.30	
Cutting 8	1.30	
Welding 1	2.30	68.15
Welding 2	2.30	
Welding 3	2.30	
Welding 4	2.30	
Welding 5	2.30	
Painter	7.00	
Dryer	7.00	
Colour blender	20.00	
Pink Packing	5.00	
Purple Packing	5.00	

2.3.5 Evaluation and selection of factory layout

The three alternative layouts are compared together by using cost per unit and number of risk points of Covid-19 contraction of workers in the layouts. The first layout is built according to primitive internal transportation. The second layout is added of the social distancing on the internal transportation. The third layout is set to use the AGV on the internal transportation.

Washing hands, wearing masks, or working from home are personal precautionary measures to prevent the spread of Covid-19, that can be implemented regardless of the context of factory layout improvements. On the other hand, social distancing is necessary to modify the transportation route and production layout. Therefore, the social distancing is chosen as the primary decision to select the plant layout.

In this research, the appropriateness of production layouts can be considered according to production capability and ability to reduce the risk of Covid-19 contraction through social distancing methods.

2.3.6 Applying of Augmented Reality (AR)

The steps of applying AR firstly use the CAD Exchanger Program to convert 3D images into ".obj" files type, then the images are able to be imported into the unity program. Secondly, the image databases is prepared for using in the mobile phone. Finally, 3D image is exported from the unity program and the layout is simulated by using simulation software (the application on the mobile phone).

2.3.7 Summary of improvement guidelines

From the problem's analysis, the summary of improvement guidelines is proposed as follows. Firstly, simulation is applied to analyze and improve worker's functions and walking paths. Secondly, the factory layout is developed by aiming to reduce costs and increase productivity. Thirdly, the risk of Covid-19 contraction in the factory is reduced by using social distancing violation measures. Finally, the 3D AR is utilized to make a clear overview of the assembly and packing methods.

3 Results and Discussion

The 3D digital mock up simulation software is able to analyze bottleneck and break-even point. This section compares the result of three layouts in terms of economic analysis, that including investment cost, cost per unit, yield and break-even point. The factory safety in each workstation is also investigated.

3.1 *The simulation software results*

The first overview layout is designed due to the traditional factory (Figure 3). The worker activities and transportations in each manufacturing station and between stations are simulated in red lines in Figure 4. Meanwhile, the simulation creates the red points according to workers, who are closer than 1.5 m to each other in a day as without social distancing rule points and they are counted in Figure 5. The result of the first layout shows that the investment cost is 1.22 million USD, the cost per unit is 154.1 USD, the yield is 518 units, the break-even point is 25,354 units and the points of Covid-19 contraction without social distancing is 21,272 points per day.

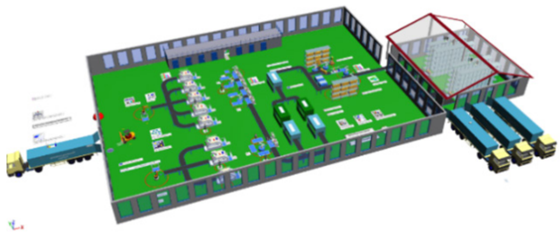


Figure 3: The first 3D overview layout.

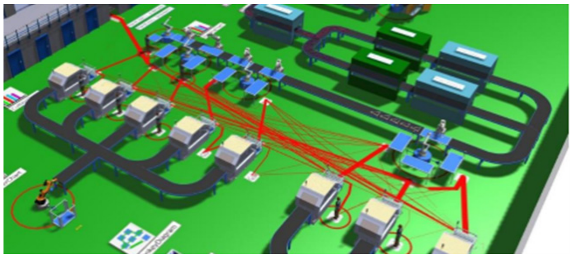


Figure 4: The walking path of workers of the first layout.

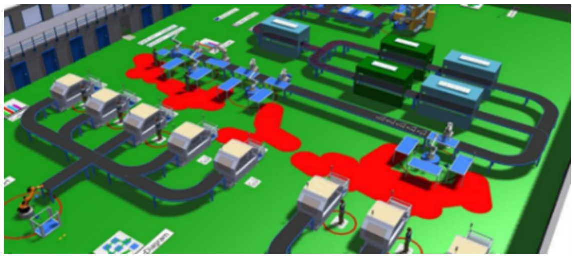


Figure 5: The points of workers who are closer than 1.5 m of the first layout.

The second layout, the work stations and the route paths of workers are rearranged due to the possibility of an area using and the social distancing rule. The second layout is shown in Figure 6 and the worker's routes are shown in Figure 7. Then the points of workers who are closer than 1.5 m of the second layout are shown in Figure 8.

The result of the second layout shows that the investment cost is 1.21 million USD, the cost per unit is 154.03 USD, the yield is 518 units, the break-even point is 25,322 units and the points of Covid-19 contraction without social distancing is 2,872 points per day.

In the third layout, the worker's transportation jobs between work stations are replaced by the Automatic Guidance Vehicle (AGV) and the layout is shown in Figure 9. Almost all machines of this layout are converted to fully automatic, that can be able to

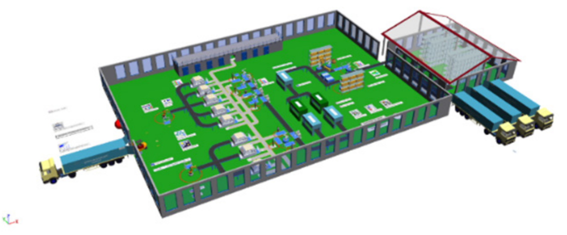


Figure 6: The second 3D overview layout.

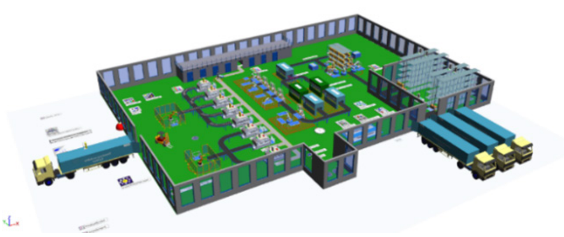


Figure 9: The third 3D overview layout.

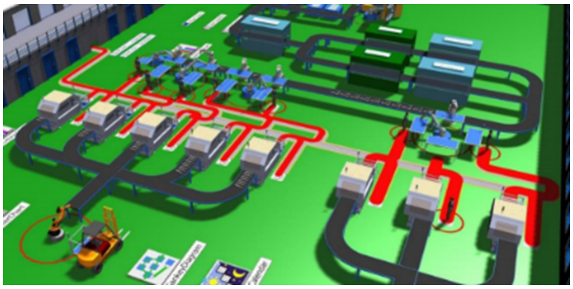


Figure 7: The walking path of workers of the second layout.

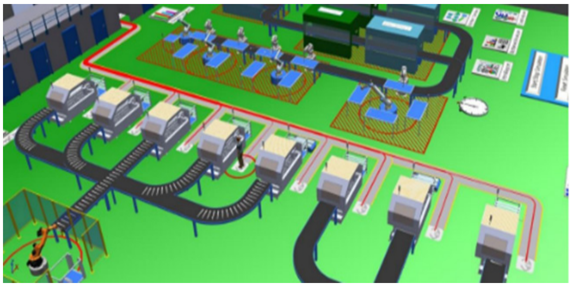


Figure 10: The walking path of workers of the third layout.

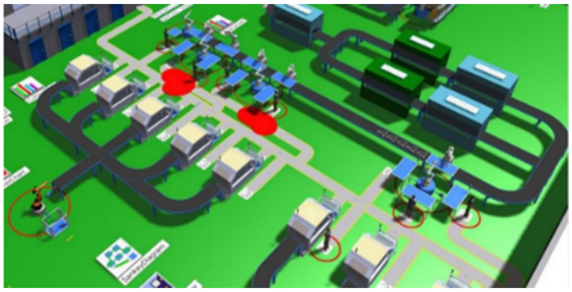


Figure 8: The points of workers who are closer than 1.5 m to the second layout.

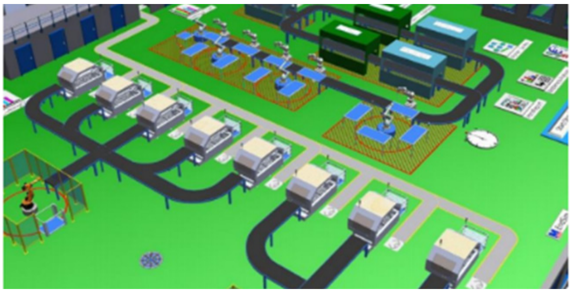


Figure 11: The points of workers who are closer than 1.5 m of the third layout.

replace workers in the production area, resulting in there is no walking route of workers except for maintenance and set up as demonstrated in Figure 10. The points of workers who are closer than 1.5 m of the third layout are shown in Figure 11.

The result of the third layout shows that the investment cost is 1.38 million USD, the cost per unit is 145.57 USD, the yield is 748 units, the break-even point is 25,354 units and the points of Covid-19 contraction without social distancing is equal to 0 point or not appeared.

The result comparison is shown in Table 4. The cheapest value for the investment cost is the second layout at 1.21 million USD. On the other hand, the cheapest unit cost is the third layout at 145.57 USD. The break-even point of the third layout generates the least amount.

Table 4: The result comparisons of three layouts

Result	1st Layout	2nd Layout	3rd Layout
Investment Cost			
(Million USD)	1.22	1.21	1.38
Unit Cost (USD)	154.1	154.03	145.57
Yield (Unit)	518	518	748
Break Even Point (Unit)	26,580	26,322	25,354

In the calculation of the break-even analysis, the price is set at USD 200, within 5 years of investment.

The example calculation of the Break-even point is below.

For example: from the first layout, the equation is

$$\text{Break}-\text{even point}=\frac{(\text{Investment Cost})}{(\text{Price}-\text{Unit Cost})}$$

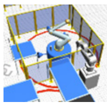
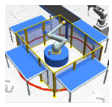
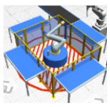
$$\text{Break}-\text{even point}=\frac{(1,220,000\ \text{USD})}{(200-154.1\ \text{USD})}$$

Break-even point= 26,580 Units

3.2 *Improving factory safety and packing using AR and Cobot*

The using of 3D digital mock up and Cobot can enhance the safety operation between human and robot. The 3D digital mock up can simulate the characteristic movement such as robot arm, moving plate and rolling of conveyor, etc. Then, the workers are able to perform and identify potential risks with robots before coming to the workstation. Table 5 shows how to improve safety in the factory. In some workstations, there are robot arms that have to work in parallel with the human, the barriers have to be installed for human protection. The workers are required to wear helmets at all times. Moreover, workspaces have to be marked so that the workers can clearly identify safety areas.

Table 5: Improvement of Cobot in DF

Risk	Before	After	Enhance
1. Robot arms			Barrier
2. Worker			Helmet required
3. Work Space			Floor Marker

At the Packing Area, Augmented Reality (AR) can be applied to demonstrate how to pack for the workers and how to unpack for the customers as shown in Figure 12. The aim of the AR is introducing to workers or customers to pack and unpack instead of human demonstration, which can be able to avoid exposure to Covid-19 contraction.

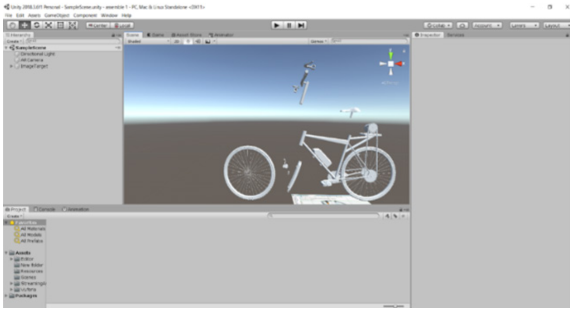


Figure 12: Augmented Reality for packing and unpacking the packaging.

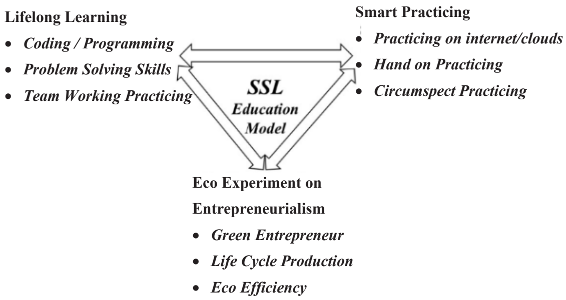


Figure 13: The smart and sustainable learning (SSL) education model.

In this research, the validation and reliability of production layout simulations can only be obtained through simulation software. This leads to the benefit of the research is being focused on the factory development results without having to modify the actual factory.

For the personal development, creating people to be ready to learn in DF environment, the smart and sustainable learning (SSL) education model, such as lifelong learning, smart practicing, and eco experimenting on entrepreneurialism (Figure 13) [12] should be applied in courses so that new engineers are equipped with modern theories and practices and are ready for Industrial 4.0.

4 Conclusions

The use of Tecnomatix Plant Simulation and Unity 3D programs can simulate the production layout. Furthermore, the layout productivities and the risk point of Covid-19 contraction can also be calculated. According to the result, the appropriate production layout is the third layout or digital factory because this layout generates the lowest break-even point and the yield of the production is increased from 518 to 748 units, or the yield value is added 44.4% over the traditional layout. In regards to the epidemic, the digital factory has a very low risk point of Covid-19 contraction from the analysis of social distancing. Therefore, the merits of this research are that the 3D digital mock up with AR and Cobot in simulation can support the decision of the plant layout according to the appropriate production situation. There are, however, the feasibility factors of building each production layout, especially safety in a digital factory should be studied further.

On the other hand, the traditional machine with some humans in the production process has been replaced by the automatic machine such as AGV. Then the 3D mock up simulation by using AR and Cobot can be able to simulate the machine movement on the work station platform, which can analyze the safety of workers in the working area with robots.

Furthermore, the benefit of using a 3D digital mock up and AR in a digital factory can introduce workers and customers to pack or unpack the bicycle, and this application can be enhanced further in the future.

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