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Dear Colleagues,

In the second half of 2020, The International Scientific Journal of Engineering and Technology (ISJET) would be four years old, and it is a pleasure to present the second issue of 2020. This new issue of ISJET highlights multidisciplinary contents, which include six original research articles involving with a work related to an optimization for production planning, a steel tube production planning and scheduling, an effect of gamification on education, a bullwhip effect prediction in a single echelon supply chain, a factors influencing the microstructure and corrosion resistance of austenitic and duplex stainless, and an augmentation for image classification.

I would like to take the opportunity to thank all of those who have contributed to our journal. All authors and readers from around the world are invited to visit the website https://www.tci-thaijo.org/index.php/isjet/index. This link will grant you submit your research to publish in our journal or will access to electronic versions of all issues of our journal. I look forward to hearing from you.

With kind regards,

Dr. Tantikorn Pichpibul
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A Simulation-based Optimization for Production Planning of Dedicated Remanufacturing System

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Abstract—**This paper presents a study of a dedicated remanufacturing system using a simulation-based optimization approach. The remanufacturing system performs various rework processes such as inspection, assembly, disassembly, testing, and repair on used-products and transforms them to be as-new products. In this study, the original production line of this dedicated remanufacturing system is shared with multiple products and has a limited space to accommodate arriving used products. Therefore, an appropriate inventory capacity should be set and a proper switching rule should be introduced to set up the production line. Otherwise, excessive line switching time and cost would be incurred. The objective of this study is to sequentially improve and suggest a method to optimize the production planning of this dedicated remanufacturing system under uncertain conditions, i.e., uncontrollable product arrival and stochastic operational time. A case study is used to demonstrate and identify possible solutions, to show the advantages of the proposed approach. This approach can assist in decision making for the planning and management of remanufacturing systems.**

Index Terms—**Meta-Heuristic Algorithm, Production Planning, Remanufacturing System, Simulation-Based Optimization, Switching Rule**

I. Introduction

Remanufacturing is a critical choice that can help to reduce the wastes that are generated from manufacturers. Remanufacturing systems are viewed as green processes that could develop environmental sustainability and economic growth. It is a significant market strategy that can avoid adverse effects (which impact the environment) and make more profit for manufacturers [1].

Remanufacturing can be separated into two different strategies. The first strategy is a combined model where the original manufacturer operates the remanufacturing, combined with their normal production processes. This strategy is mostly used in European countries [2]. The second strategy is a dedicated model where remanufacturing is operated by third-party remanufacturers. This dedicated outsourcing is more capable and productive, in terms of the collection and recovery of used products. The third-party remanufacturers have more knowledge in recovery processes, which can minimize the waste and operate with full capability in the recovery of used products.

This paper presents a study of a dedicated remanufacturing system. It operates under different used-product conditions such as different patterns of arrival and different priorities for each product type. This study provides an in-depth analysis of a dedicated remanufacturing system, concerning the material flow, remanufacturing process, and associated problems. A simulation-based optimization model is applied to find and optimize the significant factors that can affect the efficiency of a dedicated remanufacturing system of electronic products. A meta-heuristic algorithm is introduced to determine the optimal operating parameters that yield the near or possibly highest, system profit.

The remainder of the paper is organized as follows. The literature review, which consists of a review of a remanufacturing system, uncertainties in remanufacturing, and system optimization, is provided in Section II. Section III explains a simulation-based optimization approach for the dedicated remanufacturing, including an objective function and the OptQuest optimization tool. Section IV illustrates a case study including the model parameter assumptions, decision variables, and simulation model. Section V presents the results and discussion of this study. Finally, Section VI provides the conclusion and recommendations for further study.

II. Literature Review

A. *Remanufacturing Systems*

Remanufacturing systems have been studied by many researchers in the past because they can make more value for used products, reduce production costs, and promote environmental sustainability. Remanufacturing, which is an industrialized circular economy, can be considered an important solution to environmental degradation and global warming [3]. For the automotive industry, a remanufacturing system can help reduce the costs of manufacturing by up to 50%, the consumption of energy by up to 40%, and consumption of materials by up to 30%, as compared to manufacturing with new materials. Therefore, it can provide benefits in both environmental and economic aspects [4].

Regarding research on remanufacturing systems, Fathi et al. [5] studied a remanufacturing system that has two streams of used products, which are remanufactured with a dedicated capacity and a merged capacity. They used different variability levels including (1) high variability in returned product arrival that follows a hyper exponential renewal process, and (2) low variability in returned product arrival that follows a Poisson process. The total expected profit of the remanufacturing system was optimized, and the important effects of the model parameters on the admission decisions were illustrated.

B. *Uncertainties in Remanufacturing Systems*

A significant problem in remanufacturing systems is their inherent uncertainties, which make planning more difficult. A major drawback of a dedicated remanufacturing system is the incoming flow of arriving used products that is not stable and not certain [6]. For a dedicated remanufacturing company, the arrival pattern of used products is uncontrollable. Used products have a variety of product types with different residual values. Therefore, the production planning and control of such a dedicated remanufacturing system are more complex because of the effects of high uncertainty and variation. Daniel and Guide [7] built production planning and control activities for remanufacturing where the production planning and control activities are more complex for remanufacturing companies due to uncertainties. These uncertainties are stochastic returned product arrival, return unbalancing, demand rates, and the unknown conditions of returned products. Fang et al. [8] considered a hybrid production system of new and remanufactured products with two production processes. For optimizing the hybrid production strategy, the recycling uncertainty, demand rate, limitation of capacity, component durability, and differences between new and remanufactured products were considered to obtain the lowest costs in the system.

Wang and Huang [9] explored an optimal disassembling policy under demand uncertainty. They illustrated that after the disassembly process, the used products can be fixed and sold to the secondary market, or remanufactured, or reused to gain raw materials, or discarded. They applied a two-stage robust programming model to find the recycling volume and recovery strategies. Shabanpour and Colledani [10] varied the used-product conditions that affect the remanufacturing efficiency and profit to find the optimal design of a disassembly line under the uncertainty of disassembly processing time. They applied a mathematical optimization model to maximize the profit and optimize the sequence of disassembled components, assignment of disassembly tasks to workstations, and allocation of buffers.

C. *System Optimization*

Optimization can be divided into two groups: mathematical or analytical optimization and simulation-based optimization. Each method has its advantages and disadvantages, depending on the usage purpose. The mathematical optimization model can get the global optimal solution, but it is more difficult to build when the problems are under uncertain conditions. Simulation-based optimization is suitable to solve big problems under uncertainties in which they are too complex or too difficult to be solved by the mathematical models. However, it may not get the global optimal solution.

1) *Mathematical Optimization*

A mathematical model can normally be used to solve certain optimization problems. It can be solved with a single objective function or multiple objective functions in both deterministic and stochastic (within a certain level) situations. There are many mathematical methods such as Linear Programming (LP) model, Integer Programming (IP) model, and Mixed Integer Linear Programming (MILP). Lee et al. [11] explored the organization and design of a chilled water network with improved efficiency, using mixed-integer nonlinear programming models to solve the problem. Their objectives were to improve the flexibility of the network and reduce the complexity of the network. Tahirov et al. [12] constructed a mathematical model for a remanufacturing system to find which strategies (among pure remanufacturing, pure production, and mixed production) are more workable for multi-items with returned subassemblies.Nuamchit and Chiadamrong [13] then used the possibilistic linear programming approach to optimize a problem of hybrid manufacturing and remanufacturing systems by incorporating fuzziness of data,represented by the triangular distribution in their mathematical model.

2) Simulation-based Optimization

A typical simulation model can only simulate a system of interest but it cannot provide an optimal solution to the problem. Therefore, simulation-based optimization embedded with meta-heuristic algorithms is applied to simulate the model and seek the near or possibly optimal solution. Meta-heuristic algorithms, such as Simulated Annealing (SA), Tabu Search (TS), Scatter Search (SS), and Genetic Algorithm (GA) are popular among researchers. Simulation-based optimization has an advantage over the mathematical optimization due to the fact that it can optimize big and complex problems, especially with the NP-hard problems as well asit can solve the problems under a wide range of uncertainties. However, its results cannot always guarantee the optimal solution.

Mazzuco et al. [14] applied simulation-based optimization with SA to the vehicle routing problem. They optimized the product delivery schedules, to find the best route that reduces the cost, delivery time, or distance. Chu et al. [15] applied simulation-based optimization with a cutting-plane algorithm to multi-echelon inventory systems, which are under uncertainty. They minimized the inventory cost while sustaining satisfactory service levels, quantified by the fill rate.

3) OptQuest

In this study, a simulation model of a dedicated remanufacturing system is built and simulated by the Arena simulation program, which has optimization software, "OptQuest". OptQuest is a meta-heuristic algorithm that combines three meta-heuristics which are a neural network, Scatter Search (SS), and Tabu Search (TS) [16]. Jie and Li [17] used OptQuest to solve and optimize the (s, S) inventory model. They showed that OptQuest can effectively solve the stochastic constrained optimization problem. Sadeghi et al. [18] studied a three-echelon supply chain system of a blood sugar strip manufacturer. They used the OptQuest in the Simio software package to optimize the inventory factors and cell utilization to minimize the total costs. Their results showed that the Re-Order Point (ROP) values generated from OptQuest are different from the ROP values from mixed-integer linear programming. However, the results are more realistic, as uncertainties in the supply chain can be included.

III. Simulation-Based Optimization for the Dedicated Remanufacturing

The main objective of constructing and simulating a dedicated remanufacturing system is to identify the factors that affect the efficiency of the system. Major features in this model consist of the inventory space, number of operators in each station, buffer size in each station, and run size of each product type. These factors affect the production revenue and costs, including raw material cost, redistribution cost, remanufacturing cost, holding cost, and batch transferring cost. Considering the size of the studied problem with a large number of decision variables as well as many uncertainty conditions, it is considered to be an NP-hard problem. Hence, the simulation-based optimization is deemed to be suitable for solving this problem over the mathematical optimization.

A. Objective Function

To optimize the profit of our dedicated remanufacturing system, important control variables are separated into four categories: received arriving product inventory capacity, run size of each product type, number of operators in each station, and buffer size of each station in the production line. As the objective of this model is to optimize the profit from these controllable variables, the objective function of the dedicated remanufacturing model can be formulated as follows:

$$Max\ f(I,W,B,Q) = TR - TC \tag{1}$$

where I represents the inventory capacity of received arriving used products, $W=(w_1,w_2,...,w_n)$ represents the number of operators in station 1 to n, $B=(b_1,b_2,...,b_n)$ represents the buffer size of each station, $Q=(Q_1,Q_2,...,Q_m)$ represents the run size of product type 1 to m, TR represents the expected total revenue, and TC represents the expected total costs of the dedicated remanufacturing system. The expected total revenue is calculated as:

$$TR = \sum_{i=1}^{m}(R_i \times V_i) \tag{2}$$

where R_i is the selling price of product type i and V_i is the total amount of product type i that is remanufactured per replication length. The expected total costs are:

$$TC = C_C + C_R + C_L + C_S + C_B + C_I + C_H \tag{3}$$

where C_C is the raw material cost (including the purchasing cost of used products from consumers and the transportation cost from transporting the used-products to the remanufacturing factory), C_R is the redistribution cost that is incurred when the inventory capacity is not enough to hold the arriving used products, C_L is the labor cost (cost of operators for used products), C_S is the set-up cost (cost for setting up the production line when it is switched), C_B is the batch transferring cost (cost for handling and transporting a run size (batch) of used products from the received arriving product inventory to the production line), C_I is the operator idle cost (cost incurred when the operators in each station are free), C_H is the holding cost (including the holding cost of parts in the arriving used-product inventory and work-in-process inventory in each station, as well as inventory space cost).

B. Simulation-based Optimization with OptQuest

OptQuest combines the simulation with three meta-heuristics, to optimize the problem. It is in the ARENA simulation program. The parameters which OptQuest requires are upper bound, lower bound, suggested value, and step size value for each decision variable. For the upper bound and lower bound, there is the area for searching. It must be large enough to guarantee that an optimal solution is inside the area. In each iteration, all decision variables are generated. The decision variables are simulated, to get a value of the objective function where the decision variables and the value are a solution in this iteration. Then, this solution is used to generate the decision variables in the next iteration. For the terminating condition of the OptQuest optimization, automatic stopping of the search occurs when the objective function value has no improvement for 100 iterations.

IV. Case Study

To simulate and optimize a dedicated remanufacturing system, a case study of a dedicated remanufacturing company adapted from Li et al. [2] is used to be our base model for the experiment. In the case study, this plant recovers, reuses, and recycles two used-product types laptops and desktops. Both products are remanufactured under the same production line. Operations of the dedicated remanufacturing system consist of nine stations as illustrated in Fig. 1 product receiving, inspection, inventory handling, testing, teardown, repairing, labeling, packing, and shipping.

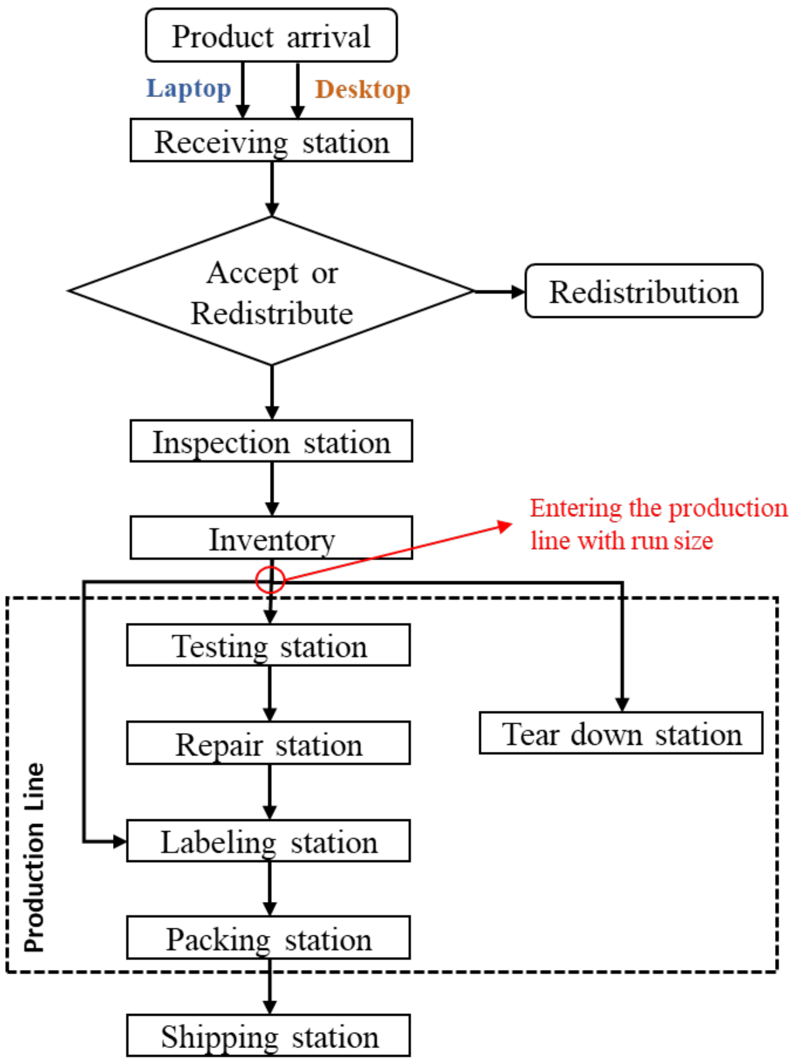

Fig. 1. Basic processes of the dedicated remanufacturing system

Product receiving is the first operation that has one receiving area to temporarily store arriving used-products. These units are transported to the receiving area by trucks. The characteristics of arriving used-products are stochastic with a variety of product types, uncertain arrival time, and uncertain quantities in each arriving batch. Then, the received product inventory is checked that it has enough space to hold the entire batch of arriving used products. If it has enough space, all arriving used products in this batch are received. If not, as many as possible used products are received considering the priority of each product type. Then, the overflow units of the batch are redistributed and a redistribution cost would incur. Next, the received products are sent to an inspection station to investigate and collect related information before sending them to the received product inventory. For the production line of this system, two different product types are shared, to be remanufactured in the same line with 5 stations. There is a proportion of products (10%) that cannot be remanufactured. These used products are sent to the teardown station for further recycling. The other used products are tested and repaired before sending them to the labeling station. In each station, there are one or more identical operators (number of operators in each station is a decision variable) working with uncertain processing time, which is exponentially distributed. The operators immediately start a job when they are available, and the product leaves a station only when the next station becomes available. Finally, the finished products are shipped out from the shipping station and sold to customers.

A. Model Parameter Assumptions

Based on the case study of Li et al. [2], the inter-arrival time of trucks, which transport the arriving used-products, follows an exponential distribution with a mean time of 4 hours, operating 8 hours a day. For pick-up trucks, parts are randomly mixed with two product types (laptop and desktop) in which the capacity of one truck equals 260 sq. ft. The size of one laptop and desktop is 0.5 and 1 sq. ft., respectively. Hence, the number of laptops and desktops in one shipment follows 0.5 x (number of laptops) + 1 x (number of desktops) = 260. Then, the number of laptops is randomized by a uniform distribution between 0 and 520 units. The number of desktops is also randomized with 260 – 0.5 x (number of laptops). The finished products are instantly shipped and sold after finishing the packaging process so there is no need to hold the finished products in the inventory. The prices of the finished laptops and desktops are $45 and $20 per unit, respectively (finished products are sold in form of semi-product components). Other parameters of the dedicated remanufacturing system are described in Table I.

1) Existing System

The inventory capacity for storing arriving used products was set to 1,000 sq. ft. The dedicated remanufacturing-system problem is to find the optimal workforce level and optimal buffer size of each station in the production line, to maximize the profit.

TABLE I
PARAMETERS OF THE DEDICATED REMANUFACTURING SYSTEM

Labor	Working time	480 minutes per day
		350 working days per year
Truck	Inter-arrival time	Exponential (240 minutes)
	Truck capacity	260 sq. ft.
	Used laptop	0.5 sq. ft. per unit
	Used desktop	1 sq. ft. per unit
Inventory	For arriving used products	1,000 sq. ft.
	For finished products	None
Production line	Setup time per switch	60 minutes
	Laptop run size	q_L
	Desktop run size	q_D
Selling price	Laptop	$45 per unit
	Desktop	$20 per unit

2) First Improvement: Inventory Capacity

After investigating the existing system, it is found that there are many overflow units from the received product inventory due to its limited space. The first improvement is to optimize the capacity of the received product inventory. Therefore, the inventory capacity is considered to be another decision variable. It is optimized to reduce the number of redistributed used products that cause a high redistribution cost. By increasing the inventory capacity, the number of redistribution units and their cost are reduced. A high immoderate inventory capacity can cause the space cost and holding cost to be too high.

3) Second Improvement: Switching Rule

The next improvement is to further improve the profit of the system and reduce the flow time of remanufacturing by applying the priority batch switching rule to optimize the run sizes of laptops and desktops for the production line. Since the production line is shared between the laptops and desktops, it needs to switch between the two products with a set-up time of an hour. This switch happens when the production line is free and all items of the current product type in the batch (run size) are finished. The priority batch switching rule is presented as follows:

a) If IL (number of laptops in the arriving used-product inventory) > qL, the production line will keep processing laptops. The priority is given to the laptops as it has a higher selling price.

b) Else if IL <qL and ID (number of desktops in the arriving used-product inventory) >qD, the production line will be switched to process desktops and vice versa.

c) Otherwise, it will wait for the arrival of laptops and desktops to complete their run sizes before the next production can be started.

B. Processing Time

Table II presents the processing time of each station in minutes. The processing time of operators in each station of the production line is assumed to follow an exponential distribution, which is applied when it is expected that they have a large variation [19].

TABLE II
PROCESSING TIME FOR EACH STATION AND EACH PRODUCT TYPE

Station	Mean processing time (minutes)	
	Laptop	Desktop
Receiving	3.24	3.24
Inspection	1.05	1.23
Inventory	0.543	0.543
Testing	6.5	7.32
Repairing	15	20
Labeling	5.66	5.66
Packing	9.146	9.146
Teardown	5.025	5.725
Shipping	1.65	1.65

C. Remanufacturing Costs

The operating costs that are related to this dedicated remanufacturing plant are presented in Table III. The raw material costs of arriving used products are estimated to be \$20 per laptop and \$5 per desktop. The redistribution cost is incurred when the arriving used-product inventory does not have enough space to hold the arriving used products for the current batch. The redistribution cost is \$5 for a redistributed laptop and \$1 for a redistributed desktop.

The remanufacturing costs of the system are separated into four parts. The labor cost is \$15 per hour per operator for the inspection, inventory, testing, and repairing stations and \$12 per hour per operator for the receiving, teardown, labeling, packing, and shipping stations and also the production line switching. The set-up cost is incurred when the production line is switched. This set-up cost is \$150 per time. The batch transferring cost for internal logistics and transferring equals \$50 per batch. The last cost is the labor idle cost that is incurred when the operators in each station are free. This labor undertime cost is 30% of the normal labor cost.

The inventory holding cost is divided into two components. The first component is the cost of capital for holding the arriving used products in the received product inventory and work-in-process inventory in each station. This component equals 50% of the selling prices per year. This is based on the value of the units held. The other component is the inventory space costfor storing arriving used productsthat is \$0.15 per hour per sq. ft., which depends on the space occupied by the inventory. This component represents the construction cost of the inventory space that needs to be built for holding the inventory.

TABLE III
RELATED REMANUFACTURING COSTS

Raw material cost (C_C)	Laptop	\$20	per unit
	Desktop	\$5	per unit
Redistribution cost (C_R)	Laptop	\$5	per redistribution
	Desktop	\$1	per redistribution
Remanufacturing cost	Labor cost (C_L)	\$15	per hour per operator
		\$12	per hour per operator
	Set-up cost(C_S)	\$150	per time
	Batch cost (C_B)	\$50	per batch
	Idle cost (C_I)	\$4.5	per hour per operator
		\$3.6	per hour per operator
Inventory cost (C_H)	Holding cost	50% of selling price	per year
	Space cost for the received product inventory	\$0.15	per hour per sq. ft.

D. Decision Variables

To optimize this dedicated remanufacturing system, ten decision or control variables are searched for their optimality by OptQuest: (1) the capacity of inventory, (2) the buffer size of the repairing station, (3) the buffer size of the labeling station, (4) the buffer size of the packing station, (5) the number of operators in the testing station, (6) the number of operators in the repairing station, (7) the number of operators in the labeling station, (8) the number of operators in the packing station, (9) the run size of laptops, and (10) the run size of desktops. The required decision variables in each model and their bounds are shown in Table IV. The bounds of all control variables are affirmed to certify that the optimal values are within these bounds.

TABLE IV
DECISION VARIABLES AND BOUNDS OF EACH SYSTEM

System / Control variables	Existing System	First Improvement model	Second Improvement model	Bound Lower	Bound Upper	Unit
Inventory capacity	-	✓	✓	1	2,000	Sq. ft.
Buffer size of repairing station	✓	✓	✓	0	50	Units
Buffer size of labeling station	✓	✓	✓	0	50	Units
Buffer size of packing station	✓	✓	✓	0	50	Units
# operators in testing station	✓	✓	✓	1	50	Operators
# operators in repairing station	✓	✓	✓	1	50	Operators
# operators in labeling station	✓	✓	✓	1	50	Operators
# operators in packing station	✓	✓	✓	1	50	Operators
Run size of laptops	-	-	✓	1	250	Units

E. Simulation Model

The simulation model runs under non-terminating conditions with 10 replications. The simulation length of each replication is 42,000 minutes (3 months) and has another 42,000 minutes (3 months) for a warm-up period to generate a stable estimate of the steady-state results. Based on 10 replications, the 95% confidence interval of the flow times has a width of less than 5% of its mean. The simulation model runs on a PC with CPU AMD Ryzen 7 2700 3.20GHz and RAM 16.0 GB.

V. RESULTS AND DISCUSSIONS

The results are obtained from the simulation-based optimization by using the ARENA program to simulate the system (under uncertainties) and the OptQuest optimization tool to search and optimize the decision variables of the system, to maximize the total profit. The results are separated into three cases: existing system, first improvement model, and second improvement model.

A. Case1: Existing Dedicated Remanufacturing System

In this case, the original inventory capacity is fixed at 1,000 square feet, and there is no switching rule to switch the line between the two products. As lot-for-lot production is used, the line is switched to produce a new product when the current product is finished. This can happen quite frequently as arriving used products come randomly. However, OptQuest is used to maximize the profit of the system by determining the optimal number of operators and buffer size in each station (see Table V for the optimal settings obtained by OptQuest). For the results of the existing system, Fig. 2 shows the breakdown of the profit and costs. It shows a profit of \$168,746.41, resulting from the difference between the total revenue of \$2,039,762.50 and the total costs of \$1,871,016.09. The redistribution cost of \$11,078.10 is high since a lot of overflow units are redistributed. This is due to the limited space in the inventory capacity for new incoming used products. In addition, high set-up and batch transferring costs are a result of an inappropriate transferring batch size. In this instance, all remaining products similar to the current product in the inventory space (an entire lot of similar model) would be transferred when the current product in the line is about to be finished. As a result, there are higher batch transferring and line switching costs.

TABLE V
OPTIMAL OPERATING PARAMETERS OF THE EXISTING DEDICATED REMANUFACTURING SYSTEM

Control variables	Fixed inventory capacity (square feet)	Decision Variables: Buffer size of repairing station (units)	Buffer size of labeling station (units)	Buffer size of packing station (units)	# operators in testing station (operators)	# operators in repairing station (operators)	# operators in labeling station (operators)	# operators in packing station (operators)
Values	1,000	34	48	26	15	41	15	24

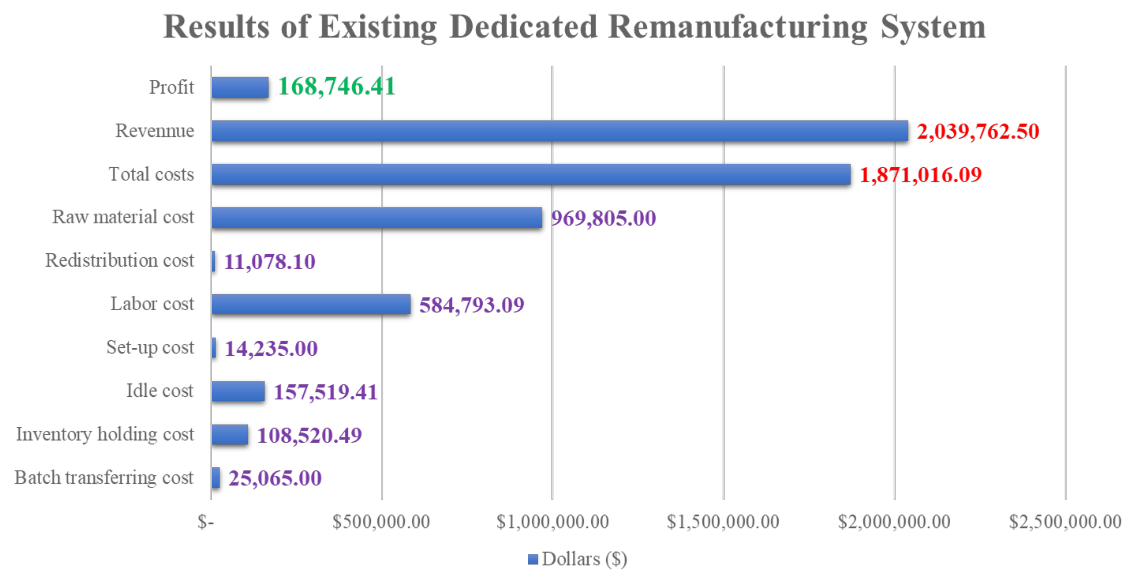

Fig. 2. Profit and cost distribution of the existing dedicated remanufacturing system

B. Case2: First Improvement Model with the Inventory Capacity

Optimal settings of the parameters in the system by OptQuest to maximize the profit are shown in Table VI. Table VII shows the costs and operating performance comparison between the existing system and the first improvement model. For a fair comparison, all models were set to have similar seeds and streams of random numbers when creating the arrival of used products. As a result, similar arrival times and the number of arriving units are created, resulting in the same raw material cost. From Table VI, it was found that the inventory capacity needs to be enlarged to 1,530 sq. ft. to accommodate the arriving batches of received products (the existing system has only 1,000 sq. ft.). This would result in a 21.28% and 66.80% reduction of the batch transferring cost and redistribution cost, respectively. This is a result of a larger inventory capacity. As a result, there would be fewer units of overflow products to be redistributed and fewer batch transferring times. However, the total revenue is higher because a higher number of units can be sent to the remanufacturing processes. From this improvement, it was found that profit can be increased by 19.67%, as compared to the existing system. However, it was also found that the average flow time in the system is much longer and the inventory cost is higher because there is more inventory at the arriving inventory area.

TABLE VI
OPTIMAL OPERATING PARAMETERS OF THE FIRST IMPROVEMENT DEDICATED REMANUFACTURING MODEL

Control variables	**Decision Variables**							
	Fixed inventory capacity (square feet)	Buffer size of repairing station (units)	Buffer size of labeling station (units)	Buffer size of packing station (units)	# operators in testing station (operators)	# operators in repairing station (operators)	# operators in labeling station (operators)	# operators in packing station (operators)
Values	1,530	42	38	47	14	39	14	23

TABLE VII
RESULTS OF THE FIRST IMPROVEMENT DEDICATED REMANUFACTURING MODEL

Profit & cost breakdown	Existing system	First improvement model	%improvement
Profit ($)	168,746.41	201,937.02	19.67%
Total revenue ($)	2,039,762.50	2,109,665.50	3.43%
Total costs ($)	1,871,016.09	1,907,728.48	-1.96%
- Raw material cost ($)	969,805.00	969,805.00	0.00%
- Redistribution cost ($)	11,078.10	3,677.70	66.80%
- Labor cost ($)	584,793.09	603,788.01	-3.25%
- Set-up cost ($)	14,235.00	11,895.00	16.44%
- Idle cost ($)	157,519.41	133,752.28	15.09%
- Inventory holding cost ($)	108,520.49	165,080.50	-52.12%
- Batch transferring cost ($)	25,065.00	19,730.00	21.28%
Operating performance			
Average part flow time in the system (minutes)	706.34	863.07	-22.19%
Average part flow time in testing station (minutes)	113.40	155.31	-36.96%
Average part flow time in repair station (minutes)	18.08	18.10	-0.12%
Average part flow time in labeling station (minutes)	6.53	6.65	-1.86%
Average part flow time in packing station (minutes)	9.82	9.75	0.69%
Number of line set-ups (times)	94.90	79.30	16.44%
Number of finished laptops (units)	36,999.00	38,217.50	3.29%
Number of finished desktops (units)	18,740.00	19,493.90	4.02%
Average inventory in the arriving inventory space (units)	412.00	541.47	-31.42%

Remarks: These results are averaged from 10 replications

C. Case3: Second Improvement Model with the Switching Rule

Table VIII shows the optimal settings of the parameters in the system. Table IX presents a cost and operating performance comparison between the existing system, the first improvement model, and the second improvement model. By simultaneously imposing the inventory capacity and run size of each product as the decision variables, the inventory cost is decreased by 17.47% from the case of the first improvement model. Even though the batch transferring cost increases by 20.73% due to a smaller inventory capacity and more transfers from the arriving inventory capacity to the production line, the average flow time has improved by 13.08%. In addition, the switching rule and appropriate run sizes help to reduce the number of line set-ups from 79.30 times in the case of the first improvement model without the switching rule to 70.00 times. This is a 26.24% reduction and significantly reduces the flow time in the testing station (77.01% reduction), which is the first station in the production line (as the entire lot would not be transferred at a time). In all, this improvement helps to increase the system's profit by 7.21% as compared to the first improvement model, or by up to 28.29% as compared to the existingsystem.

TABLE VIII
OPTIMAL OPERATING PARAMETERS OF THE SECOND IMPROVEMENT DEDICATED REMANUFACTURING MODEL

Control variables	Decision Variables							
	Fixed inventory capacity (square feet)	Buffer size of repairing station (units)	Buffer size of labeling station (units)	Buffer size of packing station (units)	# operators in testing station (operators)	# operators in repairing station (operators)	# operators in labeling station (operators)	# operators in packing station (operators)
Values	1,530	42	38	47	14	39	14	23

TABLE IX
RESULTS OF THE SECOND IMPROVEMENT DEDICATED REMANUFACTURING MODEL

Profit & cost breakdown	Existing system	First improvement model	Second improvement model	%improvement a.	%improvement b.
Profit ($)	168,746.41	201,937.02	216,487.74	7.21%	28.29%
Total revenue ($)	2,039,762.50	2,109,665.50	2,102,879.00	-0.32%	3.09%
Total costs ($)	1,871,016.09	1,907,728.48	1,886,391.26	1.12%	-0.82%
- Raw material cost ($)	969,805.00	969,805.00	969,805.00	0.00%	0.00%
- Redistribution cost ($)	11,078.10	3,677.70	4,615.60	-25.50%	58.34%
- Labor cost ($)	584,793.09	603,788.01	601,959.32	0.30%	-2.94%
- Set-up cost ($)	14,235.00	11,895.00	10,500.00	11.73%	26.24%
- Idle cost ($)	157,519.41	133,752.28	139,454.64	-4.26%	11.47%
- Inventory holding cost ($)	108,520.49	165,080.50	136,236.70	17.47%	-25.54%
- Batch transferring cost ($)	25,065.00	19,730.00	23,820.00	-20.73%	-4.97%
Operating performance					
Average part flow time in the system (minutes)	706.34	863.07	750.22	13.08%	-6.21%
Average part flow time in testing station (minutes)	113.40	155.31	35.70	77.01%	68.52%
Average part flow time in repair station (minutes)	18.08	18.10	17.88	1.24%	1.12%
Average part flow time in labeling station (minutes)	6.53	6.65	6.67	-0.29%	-2.15%
Average part flow time in packing station (minutes)	9.82	9.75	9.71	0.42%	1.10%
Number of line set-ups (times)	94.90	79.30	70.00	11.73%	26.24%
Number of finished laptops (units)	36,999.00	38,217.50	38,122.20	-0.25%	3.04%
Number of finished desktops (units)	18,740.00	19,493.90	19,369.00	-0.64%	3.36%
Average inventory in the arriving inventory space (units)	412.00	541.47	574.14	-6.03%	-39.35%

Remarks: These results are averaged from 10 replications
a. %improvement of the second improvement model as compared to the first improvement model
b. %improvement of the second improvement model as compared to the existing system

D. *Sensitivity Analysis*

For a study dealing with the profit and cost optimization, a sensitivity analysis based on different cost structures is required to confirm the conclusion that has been made. Even though there are many costs used to calculate the system's profit, not all of them have a major influence on the outcome. Therefore, we do the sensitivity analysis on four main costs, which are redistribution cost, set-up cost, inventory holding cost, and batch transferring cost. These costs are varied ±20% from their initial settings at a time, and we observe the outcomes from varying these costs. Table X presents the profits obtained from varying these costs in each model, relative to their initial values. The overall results show that the second improvement model still outperforms the other models, in terms of a higher profit, despite varying these four costs by up to ±20% from their initial values. This can confirm the appropriateness of our findings and conclusion. For instance, when the redistribution cost and set-up cost are reduced by 20%, this should favor the existing system as it has many redistribution units due to its small inventory capacity and a greater number of line set-ups. However, its profit still cannot outperform the first and second improvement models.

TABLE X
RESULTS OF ADJUSTING EACH EFFECTIVE COST FOR EACH MODEL

Effective costs		Profit ($)		
		Existing system	**First improvement model**	**Second improvement model**
± Redistribution cost	-20%	$162,052.57	$193,585.29	$220,639.19
	Initial value	$168,746.41	$201,937.02	$216,487.74
	+20%	$159,458.73	$201,987.04	$215,841.27
± Set-up cost	-20%	$180,402.29	$198,350.58	$210,759.47
	Initial value	$168,746.41	$201,937.02	$216,487.74
	+20%	$153,252.60	$194,013.04	$206,656.09
± Inventory holding cost	-20%	$192,670.35	$230,928.76	$238,784.69
	Initial value	$168,746.41	$201,937.02	$216,487.74
	+20%	$149,241.15	$162,416.73	$179,522.10
± Batch transferring cost	-20%	$177,535.81	$195,877.23	$206,093.77
	Initial value	$168,746.41	$201,937.02	$216,487.74
	+20%	$154,955.46	$188,252.47	$203,655.92

VI. CONCLUSION

The remanufacturing system has proven to help environment as well as contribute to a higher company's return. However, it is unstable and hard to control due to uncontrollable inputs. This paper purposed to explore the problems of the remanufacturing system based on a case study of a dedicated remanufacturing system. A simulation-based optimization approach was applied to this system incorporating uncertainties of part arrival and operating conditions. While, ARENA was used to simulate the system under uncertain conditions, OptQuest was used to optimize the operating parameters of the system.

A remanufacturing system helps the environment and contributes to a higher company profit. However, it is unstable and hard to control due to uncontrollable inputs. This paper explores the problems of a remanufacturing system based on a case study of a dedicated remanufacturing system. A simulation-based optimization approach was applied to this system, incorporating uncertainties of part arrival and operating conditions. ARENA was used to simulate the system under uncertain conditions, and OptQuest was used to optimize the operating parameters of the system.

A few sequential steps of improvement have been applied to the system, starting from recommending optimal buffer size and an appropriate number of operators in each station. We also enlarged the size of arriving inventory space to accommodate more arriving used products and imposed the switching rule for setting up the production line with an appropriate run size in each model. The findings showed that adjusting one operating parameter would affect the other parameters. The final step where all improvements were applied increased the profit of the system by up to 28.29% with a shorter average part flow time and fewer line set-ups. This improvement should not be the end as this method can be applied to other parts of the system. A case study is used to demonstrate and identify possible solutions and their advantages of utilizing the simulation-based optimization approach. These findings can help decision makers to make the right decisions on the near, or possible optimal, or feasible solution in a certain situation under an uncertain environment.

For larger problems with a higher number of decision variables, this simulation-based optimization using OptQuest may need some adjustments to reduce the computation time and further improve the quality of the objective value. As the meta-heuristic algorithm cannot guarantee an optimal result, alternative algorithms such as Genetic Algorithms, Particle Swarm Optimization, Ant Colony, or hybrid optimization are worth exploring, to strive for a better solution. This can be further introduced in the model to improve its effectiveness.

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A Steel Tube Production Planning and Scheduling with Product-Dependent Changeover Time Using Digital Twin

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Abstract—**Steel tube manufacturing industry is one of heavy industry that use a lot of labor, large and heavy machineries, intense capital, and high technologies. The production planning and scheduling of steel tube manufacturing is complicated because of a long tool setup time and machine conditions. Moreover, there are half-thousands of different finished goods. In order to produce efficiently and maximize machine utilization, this paper proposes a digital twin of steel tube production process focus on forming process. The digital twin could be used for planning and scheduling to manage complexity of machinery setup, priorities production, fulfil inventory without shortage and to conduct what-if analysis and compares for the scenarios of different schedules. The digital twin provides production model simulating precise production total time, tool setup time, number of products and production deadline. The simulation model is tested with forty-nine products on three identical machines with their tool setup time. It reduces the production planning time of the planning engineer and provides accurate schedule of each product.**

Index Terms—**Production Planning and Scheduling, Digital Twin, Steel Tube Manufacturing**

I. Introduction

"Digital twin" is defined as virtual simulation of physical with real environment by advance of technology such as paradigm of air force vehicles [1]. The digital twin concept is used for predicting, evaluating and analyzing the physical change by technologies [2]. In manufacturing industry, the digital twin is known as one of the industries challenging to become industry 4.0 or smart manufacturing [3]. Digital twin for manufacturing has been explicated to drive and achieve smart manufacturing [4]. Digital twin disguises shop-floor of real factories with real facility, equipment and environment before implementing [5] and applied the real factories digital twin with the new information technologies of industry 4.0 [6]. For production planning, digital twin is applied as decision support system aiming on tracking material flow and operation systems [7]. The important objective of digital twin on manufacturing is to reduce cost and accrue efficiency [8].

In steel industry, digital twin is applicable from products to services [9]. One of possible applicable area is production planning and scheduling. An optimization and a simulation are applied on steel sheet and coil production scheduling [10]. In addition, they utilize on buffers and inventories management of steel sheet production to analyze and improve the system [11]. For steel tube production, Mixed Integer Programing (MIP) is utilized for optimizing the job sequences considering on machine capability and minimum makespan [12]. On the other hand, sequence-dependent setup time scheduling problem for steel tube production is discussed and solved by heuristics algorithm [13]. In this paper, we purpose to utilize the digital twin to help improving the production planning and scheduling.

II. The Steel Tube Manufacturing Process

There are two production processes in a steel tube manufacturing process: slitting process and forming process as shown in Fig. 1 and Fig. 2. Slitting process cuts a metal sheet roll to be metal films with the specified width. The forming process takes the steel film to form tube. This paper considers forming process because of the complexity of tool setup with three machines and forty-nine of various products.

There are three types of finished products: round pipe, square pipe and rectangular pipe. In each machine, there are different tool setup time. There are twelve tools to be changed and these tools can be changed all or some of them. The products are grouped by shape or type, then they are grouped by outside dimension (OD). It takes thirty to forty minutes setup time for changing between product within the same OD group. Furthermore, different OD groups are grouped by tool group. The tool setup time in the same tool group is around one and half to eight hours and the setup time of tool changing between tool group is three to eleven hours depend on machine conditions and number of tools changed.

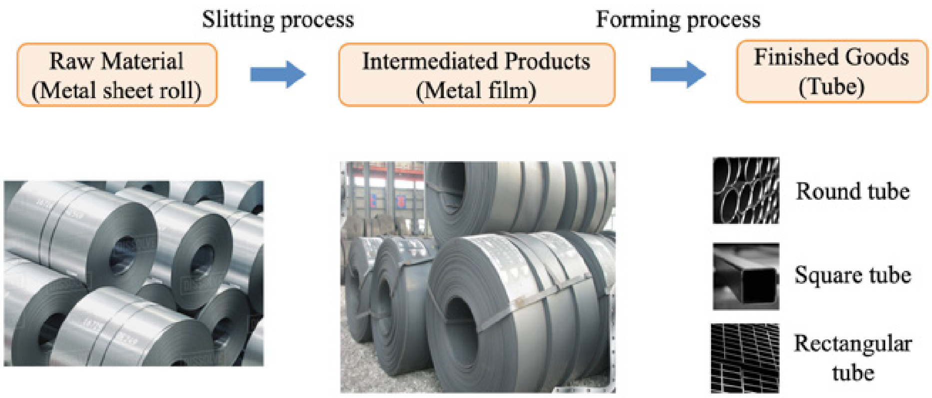

Fig.1. Steel tube production process

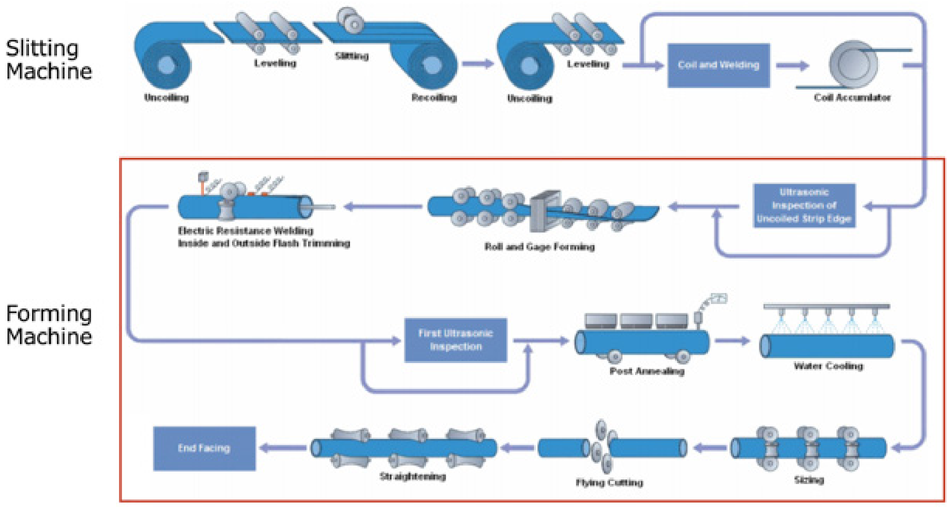

Fig. 2. Steel tube production process

III. Digital Twin of Forming Process

This section, we explain how to construct the digital twin of the steel tube manufacturing. The test data are from the actual case that there are ten forming machines with around half-thousand products. There are three identical forming machines with forty-nine products that would require the optimal scheduling that maximize machine utilization. Therefore, the heuristic method is applied to find the nearest optimal solution and the digital twin is created to represent these three identical forming machines to help identifying tool setup using the Software-as-a-Service (SaaS) on cloud, called GD.findi.

GD.findi requires the data model consist of the "floor plan" and "process plan". The floor plan specifies the factory layout including the station or machine locations and size as shown in Fig. 3. The process plan specifies the production process of each product group and each include the work time and the associated stations. Moreover, process requires the input parts and the output parts with their quantities. The production process represents each OD group where the forming process time are the same. Fig. 4 shows the example of production process that represents one of the OD groups. The detail process properties are shown in Table II.

The tool setup condition on the forming machines depends on the sequence of product. The digital twin of steel tube forming production process is created to represent the tool set up that depends on the sequence of product, the OD group and the tool group. The tool setup time can be specified once there is a change between different OD group or different production process. Table I shows the tool setup time for forty-nine products in eight OD groups and three tool groups.

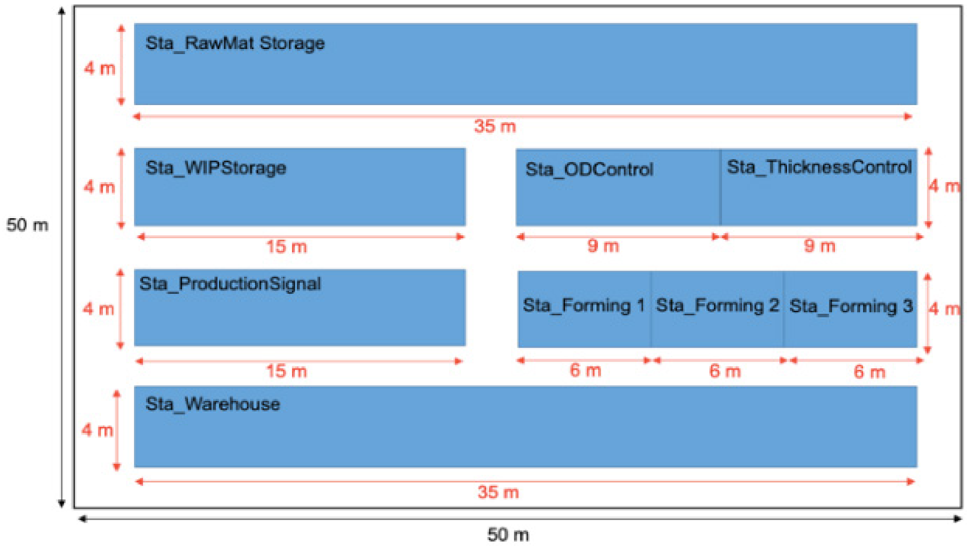

Fig. 3. Floor plan for GD.findi simulator

The Proc_ODControl and the Pro Thickness Control are created as dummy processes for tool changeover setup. The Proc_ODControl is for setting up the tool once there is a change between OD group. The Proc_ThicknessControl is for setting up the tool once there is a change in product and it takes thirty minutes setup time. If the next product is in the same OD group, Proc_ODControl setup time is 0 because it uses the same OD tool and the Proc_ThicknessControl setups the thickness tool. If there is a change of product between OD group, both Proc_ODControl and Proc_ThicknessControl will set the tool but the setup time of the Proc_ODControl covers the setup time of the Proc_ThicknessControl.

Furthermore, there is a dummy process, Proc_Signal, which is to wait for the Proc_Forming processe finished the work and send production signal to Proc WIPStorage to start its process.

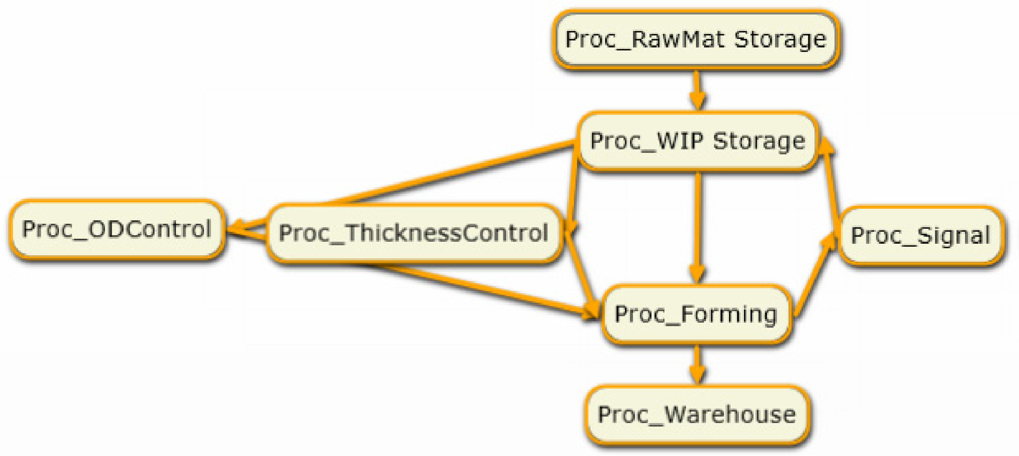

Fig. 4. Production process for one of the OD group

TABLE I
THE TOOL SETUP TIME BETWEEN OD GROUP AND TOOL GROUP

			Tool group 1			Tool group 2		Tool group 3		
			OD group 1	OD group 2	OD group 3	OD group 4	OD group 5	OD group 6	OD group 7	OD group 8
		Thickness (mm.)	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5	1.2-3.5
Tool group 1	OD group 1	1.2-3.5	30 mins	4	4	5	5	6	6	6
	OD group 2	1.2-3.5	4	30 mins	3	5	5	6	6	6
	OD group 3	1.2-3.5	4	3	30 mins	5	5	6	6	6
Tool group 2	OD group 4	1.2-3.5	5	5	5	30 mins	3	6	6	6
	OD group 5	1.2-3.5	5	5	5	3	30 mins	6	6	6
Tool group 3	OD group 6	1.2-3.5	6	6	6	6	6	30 mins	4	4
	OD group 7	1.2-3.5	6	6	6	6	6	4	30 mins	3
	OD group 8	1.2-3.5	6	6	6	6	6	4	3	30 mins
Number of products			5	6	6	7	7	9	3	6

TABLE II
PRODUCTION PROCESS SETTING

Any Production Process	Proc_RawMat Storage	Proc_WIP Storage	Proc_OD Control	Proc_Thickness Control	Proc_Signal	Proc_Forming	Proc_ Warehouse
Work time [s]	60	120	0	0	0	3600	60
Set up Time [s]	0	0	0	0	0	0	0
Frequency [N:Time] [s]	-	-	-	-	-	-	-
Input from Local In [ID/Name/ Quantity]	[RM/Raw Material/1]	-	-	-	-	-	-
Input from Previous Process [ID/Name/ Quantity]	-	[RM/ Raw material/1] [ProductionSignal/ ProductionSignal/1]	[ODSignal/ ODSignal/1]	[ThicknessSignal/ ThicknessSignal/1]	[ProductionSignal/ ProductionSignal/1]	[ODSignal/ ODSignal/1] [ThickSignal/ ThickSignal/1] [IP/Intermediate Product/1]	[FG/Finish Goods/10]
Output to Local Out [ID/Name/ Quantity]	-	-	-	-	-	-	[-/-/10]
Output to Next Process [ID/Name/ Quantity]	[RM/Raw Material/1]	[IP/IP/1] [ODSignal/ ODSignal/1] [ThickSignal/ ThickSignal/1]	[ODSignal/ ODSignal/1]	[ThicknessSignal/ ThicknessSignal/1]	[ProductionSignal/ ProductionSignal/1]	[ProductionSignal/ ProductionSignal/1] [FG/ Finish Goods/400]	-
Associated Station	Sta_RawMat Storage	Sta_WIP Storage	Sta_ODControl	Sta_Thickness Control	Sta_Production Signal	Sta_Forming1, Sta_Forming2, Sta_Forming3	Sta_Warehouse

IV. HEURISTIC FOR PRODUCTION PLANNING AND SCHEDULING PROCESS

This section explains a heuristics method for production planning and production scheduling with objectives to maximize the Overall Equipment Effectiveness (OEE) or minimize the tool setup time. The heuristics algorithm find the best production schedule and the detailed production operation is simulated in the digital twin model based on the given schedule to obtain the detailed operations and its KPIs. The steps of heuristics is used scheduling is contained as follow.

Step 0: For each station does follow the step.

Step 1: Getting the previous 2-month production sequence $S = \{P_1, P_2, \ldots, P_m\}$ of each machine.

Step 2: Identify the last product P' produced in last month. Then identify product P' in the production sequence S and continue the sequence from a product after P'.

Step 3: For each product P_i in sequence S, compute the production quantity, production start date and time, production finishing date and time, and production lead time. The production of P_i can start after the previous production finish and the tool is completely setup.

Step 4: If the production of P_i cannot produce before P_i is out of stock, swap the sequence of P_i with the product that come before P_i in the sequence S base on the following priority.

- Swapping product P_i with the product that come before P_i within the same OD group.
- Swapping the whole OD group that contains product P_i with the other OD group that come before but within the same tool group.
- Swapping the tool group that contain product P_i with the other tool group that come before.

Step 5: Recalculate production quantity, production start date and time, production finishing date and time, and production lead time of all of products that swap the position in the sequence.

Step 6: Repeating from step 3 until all products can be produced before they are out of stock.

After getting production schedule from the heuristic step, the production schedule are assigned in digital twin model that was created in GD.findi as shown in Fig. 5. The digital twin model with the production schedule is simulated and return the KPIs to check quality of the schedule. The KPIs include OEE, utilization efficiency, machine capability, process capability, and production ratio.

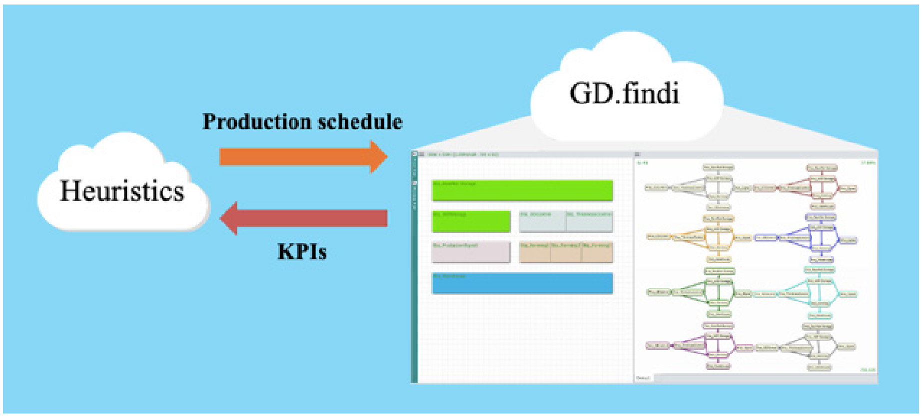

Fig. 5. Heuristics and GD.findi information transfered

V. Results

Once the digital twin of the steel tube production is created, various production schedules are tested with forty-nine products of eight OD groups and three tool groups. The production quantity are 500 kilograms for each product. The computational time for the heuristic and simulation takes about 2 minutes per each schedule. The manual scheduling takes around one to two days. Moreover, the planner could conduct what-if analysis to compare between various schedules and scenarios within the reasonable time. The comparing of computation is shown in Table III. The best schedule is when the sequence is arranged by grouping the product in the same OD group. Then the products with the same tool group are arranged in sequence. The example of the nearest optimal sequence is shown in Fig. 6. This optimal sequence provides the highest OEE. The nearest optimal result of the tested data using the digital twin is shown in Fig. 7.

TABLE III
COMPARING AVERAGE COMPUTATION TIME

Data	Average computing time (minutes)	
	Manual	Heuristics and digital twin
Test case	720	2.06

VI. Conclusion

The steel tube manufacturing has long tool setup time and long production time with expensive machine. Their tool setup time and machine conditions for the forming process are complex. The production planning and scheduling of the forming process for around five-hundred different products could take two to three days to do it manually. Consequently, the digital twin of the forming process for the steel tube production is proposed for production planning and scheduling to improve making decision. This steel tube production digital twin is evaluated with the example of forty-nine products, eight OD groups and three

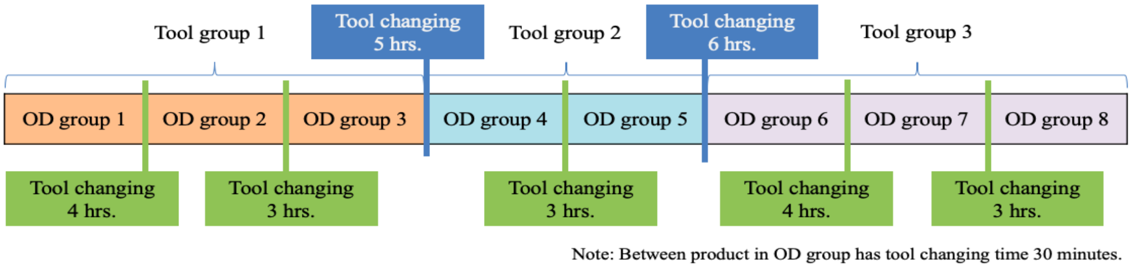

Fig. 6. The example of the nearest optimal production sequence with tool setup time

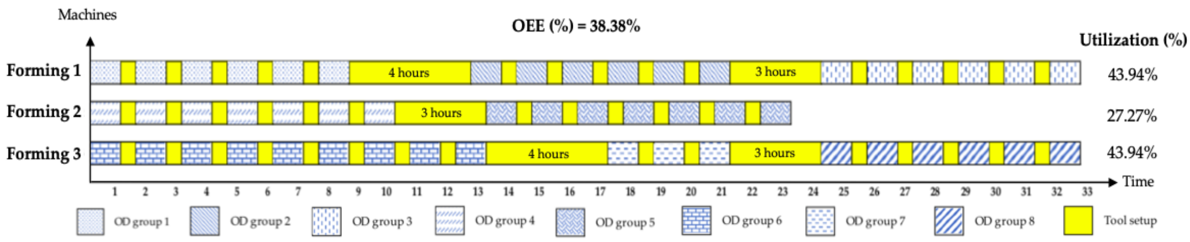

Fig. 7. The optimal Steel tube production scheduling with tool setup time

tool groups. The heuristic for production planning and scheduling is applied to find the nearest optimal production sequence. The results of digital twin show the exact schedule with number of products, total production time, tool setup time and production start and end time. This tool helps the planner to make the decision with less planning and scheduling time than planning manually. Furthermore, it serves to manage machinery and tool setup, prioritize the production and satisfy inventory level. For future research, the improvement of heuristics for production scheduling should be explore and utilize this digital twin. Moreover, the Artificial Intelligent (AI) techniques should be explore to improve quality of schedule.

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An Effect of Gamification on Education under Online Lives Teaching

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***Abstract*—It is necessary for traditional offline teaching to be transformed into online teaching to continue education during emergencies. The technology is ready for the transition of teaching from traditional classes to online classes. However, it is difficult to achieve successful online live teaching due to several factors, including distraction, motivation, and self-directed learning of the learner. Therefore, gamification has been selected to apply to online live teaching. By applying the game mechanic including game and reward system, this motivates the learners and increases their participation. The result illustrates that gamification can help increase participation and motivate learners in online teaching compared to in-class teaching. Moreover, by extending the research to apply gamification to pure online lives teaching, the result shows that it is guaranteed to help motivate the learners to attend the classes, participate in activities, and make discussions, thus increasing the understanding of course materials reflected by the activities and quiz scores. This fact shows that gamification is necessary for online live teaching which can help support motivation and increase participation in online live class learning.**

***Index Terms*—Gamification, Education, Online Teaching, Live Teaching, Participation**

I. Introduction

Education is a key to future career success. Many academies have shifted offline or traditional learning on to online learning to meet the need of education for various type of people. In an online learning or e-learning, learner can study at any time and any place that the learner prefers at their own pace. This is the ideal education for people that seek higher or various knowledge such as people who are looking for reskill, skill upgrade, higher degree, etc. This can result in getting promoted to a higher position or receiving higher salary [1].

The success of online learning is based on the five dimensions including self-directed learning, motivation for learning, computer and Internet self-efficacy, online communication self-efficacy, and learner control [2]. The issue of learner motivation and responsibility is crucial which make it sometimes difficult to complete the course due to other attraction. Besides, many people including teachers, students, and parents still prefer the traditional method where learners attend the academy for learning and socializing.

However, in the year of 2020, due to pandemic outbreak, the Corona virus,many places have been requested to temporary shutdown to avoid virus spreading including the academy. Such action forcedmany of the academies to transform traditional teaching into online teachingand lives teaching online. The method of transformation might be simple however to accomplish the result might be difficult due to many factors including class attendance and participation. Since the learning takes place online, some learner might turn on the tool that used for teaching to make it look like attending the class while they somewhere else. Other factor, such as a class duration of up to three hours, can bore students if there is no activity or participation which can result in falling behind the class content and losing interest in the class. Online participation is needed for the lecturer to receive the feedback from learner whether he or she understand the course material. However due to online system where lecturer cannot see the whole learners, this might be difficult to get the feedback.

Therefore gamification can be used as a solution to increase participation and motivation of the learners to study in the live teaching online. By applying game mechanic of gamification to the lives teaching class, this can increase participation by making the class activities more entertaining. The purpose of this research study is to study the differencein live teaching online with and without gamification. Its aim to present how gamification can motivate and increase participation of learners in live teaching online.

II. Literature Review

Online learning or e-learning can be described as the use of the Internet and other related technologies to deliver, support, enhance teaching, learning, and assessment [3]. There are various ways to construct an online course such as providing course material on the internet for the learner to download and study on their own. Some online courses are recorded while the lecturer is teaching the class and are provided online for better understanding. In some classes, the lecturers are using programs to setup virtual classrooms and live teaching learners online.

For online learning to become a successful, the learner also play an important role as well. The learners are required to have technical skills related to use of computers and the Internet [4]. Also, the learners are required to have five readiness as follows [2]:

- Self-directed learning is the learner takes responsibility to study and understand their learning. This is because, by shift to online learning, it has provided more flexibility which the learner is no longer bound to attend the class. So, the learners must be responsible to the task of completion. The responsible learner or learner with the high level of self-directed learning are more to be success in online learning.
- Motivation for learning is the urge to study with enjoyment which is very important in online learning system. This is because through online, learning can be distracted by multiple things such as game, movie, song, shopping, etc. These distractions can distract the learner's attention during online teaching.
- Computer and Internet self-efficacy is the skill of the learner on using computers and the Internet to complete a task. This is because the learning, work, assignments, and other course related material will be needed to accomplish online through the online learning system.
- Online communication self-efficacy is the ability of learner to communicate in online settings.
- Learner control is the degree that learners can control their learning experiences such as pace and content of studying.

The learner with high level of these five-readiness dimension can perform much better in the online learning setting. However, in the world today where everyone has a smart device and the internet in the palm of their hand. It can be difficult for the learner to be concentrate on the online learning for an hour or more. The smart device grants the access to various entertainment including game, movie music, chat, social, shopping and many more. So, with these distractions it can be hard for learner to keep their concentration and participation in the online teaching classroom.

Thus, the gamification was choosing as a solution to apply to online learning or lives teaching online to motivate and keep students participating in the online setting. Gamification is to apply the game mechanic to the processes or activities which aim to increase participation [5]. By using game mechanics to make the activities become a game, which will make the participant participate and enjoy. The concept of gamification can be applied in various ways such as applied in education [6], social media marketing [7], corporate social response [8], etc.The concept of gamification are:

A. Game Mechanics

Use of game mechanic such as level, point, reward, etc. in the activity or process. By applying the game mechanic to the activity, this helps stimulate the participant to participate in the activity and result in increasing engagement and involvement of the participants toward activity. For example, by applying the prize or reward system to an activity, it will attract the participants to participate to achieve the reward by completing the achievement.

B. Experience Design

Design the activity or process into a game that participant will feel like playing a game while doing the activity or process. For example, design a story and applied to activity, format of game and activity, how to play or how to complete and earn achievement. A well experience design will help the participant feel like he is a part of the activity or playing a game rather than doing a regular activity.

C. Digital Engage

Developing the attachment mechanism to the activity or process to attach the participant with the activity or process to complete the goal. This is because the time requirement for game completion varies on each task. Some of tasks might take less time while other might take longer for completion. In the case of the long task, participants might get bored and lose interest in the task and activity. So digital engage is needed to keep participants to keep on going to complete the task or activity. Also, it should not be too complicated for participants to follow or understand otherwise participants might feel it is hard and will be uncomfortable to go on with it.

D. Motivate People

A regular work or task might not be interest for participant to complete. However, through the game mechanic participant will be motivated to complete the activity or task. The game design and reward system will the motivate participant to complete to gain the achievement. Also, the game system can be developed into a competition, where participant will be motivated to complete with others for high rank or reward. For example, the participant is motivated to develop new ideas or innovations to complete the task to gain bonus.

E. Goals Achievement

Create a goal for task completion as an achievement. The game mechanic should be able to support and guide participants to complete the goal. The reason that the guideline or support is needed because some part of the task or activity might be complicated which the participant might not be able to complete it.

By applying gamification concept to task or activity, this will make the task or activity more challenging and entertaining. This method can gain attention of the participants and increase in participation.The participant will be willing to complete the task for their own enjoyment. It will motivate participants to complete the task and achieve the goal.

III. Methodology

An online learning such as live teaching, which lecturer gives lecture by live lecture online through program or software. This can be the answer for learner that have difficulty to travel or attend the class. The success of online teaching is not relied on how well the lecturer giving a lecture, but it is also based on how the learner learns as well. The learner with high level of self-directed learning, motivation for learning, computer and Internet self-efficacy, online communication self-efficacy, and learner control are certain to complete the online course. However not all the learners are the same. Some of the learners might be lack of self-directed and got attract to other activity and become less participate in the course. This can make an online course a negative experience for the learner.

To solve the issue, gamification has been applied to the course. The purpose is to make learning as fun as playing a game. This will make online live teaching course become more interesting with the aim to increase participation of learners in online class. The component of gamification has been adapted and applied to the course are as follows:

A. Game Mechanics

Applied the reward system to online class's activities. The rewards are divided into each activity in class such as class participation, class exercise, etc. Reward including present such as doll or pen, extra points, extra time on the exam. The reward system will motivate the learners to participate because they will receive something back in return which aims to increase participation in online course. The game mechanic will help support the learners which low level of self-directed learning to have a focused on the course and support motivation for learning. It might not train the learner to be more responsible however it will help the learner to participate to be able to get the reward.

B. Experience Design

The content of course is modified into a story and the activity becomes a challenge or task that leaners must complete to continue the story. Like game that can be multiple routes in the story, the result of task completion will also be different so the learner can get the experience while learning. This can help support motivation for learning and learner control.

C. Digital Engage

Gaming is fun, however it might not be fun when donefor a long period of time. Digital engagement is needed to keep the learner's retention on online course or during the lives teaching. In this case, the platform for online lives teaching play less important row due to limitation in teaching online. So, the reward system will have to be involved to create digital engagement. For example, in order to get thereward, the learners will have to attend several classes to earn a token. Once they collected curtain number of tokens then they can exchange for the reward.

D. Motivate People

Motivation is also crucial for online learning in the present where there are so many attractions. The challenge has been applied to the online course where the learner can complete it individually and be competitive with others. The reward system is also applied to support motivation of the learners. There are multiple methods to motivate learner in this research including give away small presents to the most participate in that class period. Extra point for group where all members present online. Presentation competition which the top three groups that get the most score will receive extra time add on to the final exam and many more.

E. Goals Achievement

Each task or activity has a clear goal and achievement. The lecturer acts as a guideline or support system. In some activities, the learner can spend the point that earned to exchange for extra guideline from the lecturer.

The game mechanic applied to all course activities during the online lives teaching as shown in Fig. 1. The mechanism covers the activities prior, during, and after class to keep the learner involvement and motivate by all that present in the class will gain a token. Over the course period from week 1 to week 10, the learner will collect the token which can be exchanged based on learner preference. This is to keep learner participating in order to receive the reward.

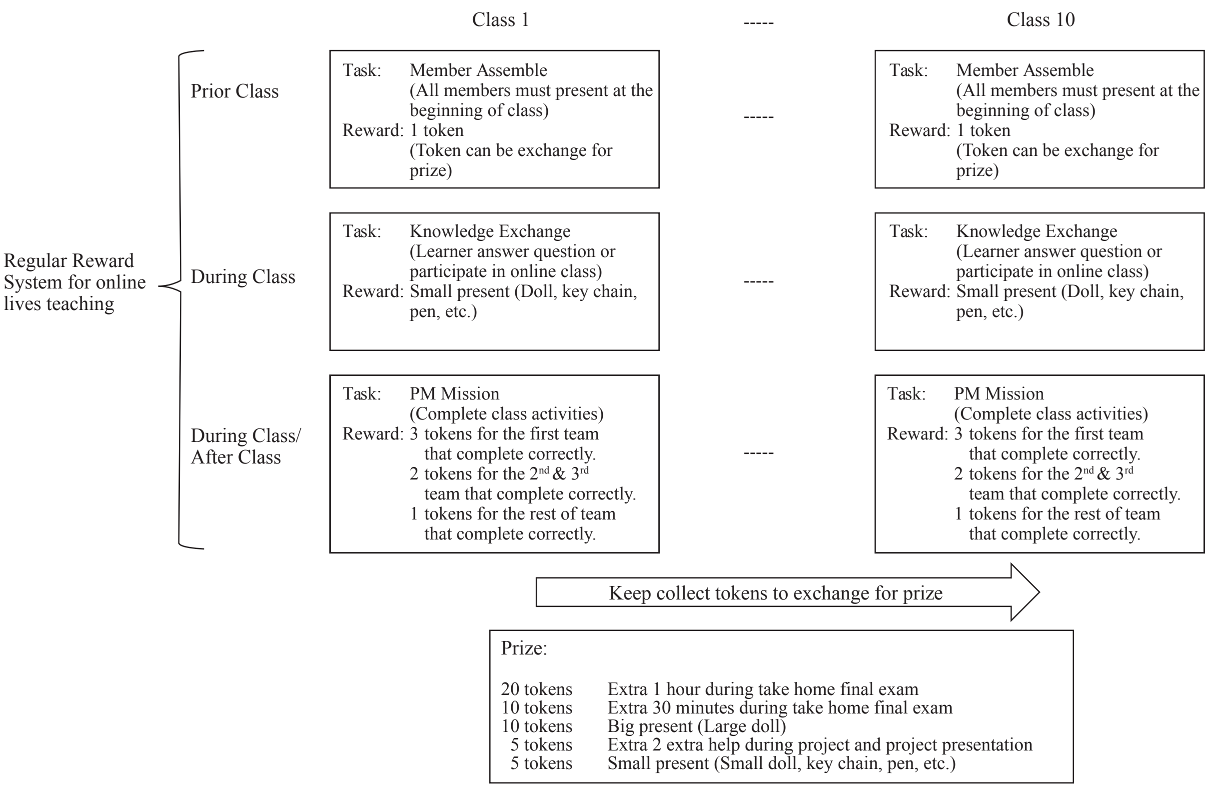

Fig. 1. Regular game reward system mechanism

Furthermore, special event is held for reward give away as best presentation award, popular vote, Q&A give away. This is an add-on activity from the regular task which aims to motivate the leaner to participate and entertain during the class. The learners that participate will get the prize right away without the need of collecting to get the achievement. The group with high performance for presentation will be judged by the group of lecturers and will be announced for the prize. During the online live teaching, there will be a critical or key question that is related to the course material, the learner that gets the right answer first will be rewarded the prize or in some cases many learners will participate in the question discussion, learners can wage their token in the choice that they believe that it is correct. The correct answer will double the tokens that learner wages. However, the wrong answer will cost them to lose the token. This mechanism adapted later to get the learner to prepare before class. The add-on reward system mechanism is shown in Fig. 2.

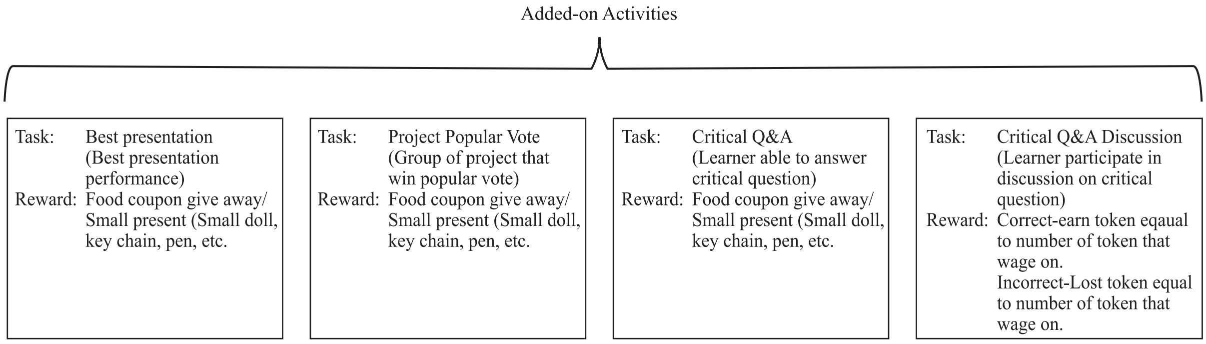

Fig. 2. Added-On game reward system mechanism

IV. Experiment: A Case Study of Lives Teaching on Project Management

Panyapiwat Institute of Management provided education from undergraduate to graduate level. The institute has an e-learning to support teaching and start to move on to massive open online course which aims to provide knowledge online for student. However, in the year of 2020, the pandemic covid-19 virus outbreak that causes the country to shut down. All businesses and corporations have been ordered to temporary suspend their business and close to prevent virus from spreading. All the academies and institutes also must close the campus to prevent virus spreading. However, the education must continue because it is in the middle of semester. As a result, the courses have to be transformed form traditional offline course into online course which learner can study from their place to prevent spreading of virus.

The course transformation from traditional to online course is not difficult. The Institute has provided the online conference program which lecturer and students can you their account to log in and access the program. This program is a tool for online learning course where teacher can give a lives lecture online with aims to make students feel like they are learning in the class as usual. This is also true for Information Technology Project Management course. The course was starting as traditional offline course where lecturer gives a lecture in the classroom. However, after the virus outbreak, the course has to be transformed to online live teaching course. The problem that arises is that not all the students/ leaners have high level of self-directed learning. Self-directed learning and motivation for learning are two of the most crucial points in online learning in the present time where student can be distracted by several of things such as online game, movie, or shopping. Computer and Internet self-efficacy is however not very crucial because all of the students are in the information technology major and are familiar with the technology and the use of Internet. After the course was transformed to online lives teaching, the participation and the average class score decreased as presented in Table 1.

Table I
Information Technology Project Management Course Participation after Transforming to Lives Teaching

Criteria	Traditional Offline Course			Online Live Teaching		
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
Number of student absent (total 36 Students)	3	1	0	7	10	12
Class Participation on discussion (Question and answer)	100%	100%	100%	80%	80%	60%
Class participation on group activity (All members participate on activity)	100%	100%	100%	80% (1 group missing 2 members)	60% (2 group missing members)	40% (2 group missing members, 1 group has 1 student)
Average activities score	82	88	87	80	71	59
Average quiz score			88			63

From collected data it can be seen that after course transformation due to pandemic outbreak, the number of absent students increased to one third of the total class number. The reason is that student who absent including due to lecturer cannot see all the student then they have no pressure to be in class, they can sleep, watching movie, play game, etc. The effect of student absence also impacts the class participation. The students with high level of self-directed participate in each of the question and activities however some student just turn on the online live teaching to make it look like they are participating in class but do other things. As for group activity which in traditional offline class all student participates in activities however in online lives teaching due to above reason, some of the group has only a single member. This is also effects the class activities and quiz score to drop down. As a result, to keep continue online lives teaching alone might not attract or interest student. It must attract and keep the student entertained to make them enjoy what they are learning. Therefore, gamification has been applied to the course.

V. Evaluation

The evaluation of the research on effect of gamification in online lives teaching was collected by monitoring the class after applying gamification.The concept and game mechanic of gamification that is described in the method has been applied to the course online live teaching. The students are interested in the story on how to evolve to become a project manager. The reward system encourages the learners eager to attend class online session and participate. The number of students attend the class goes up as well as the number of students participating in class as shown in Table II.

Table II
Result after Appling Gamification
to the Online Lives Teaching

Criteria	Traditional Offline Course			Online Live Teaching			Online Live Teaching with Gamification			
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Number of student absent (total 36 Students)	3	1	0	7	10	12	10	6	2	1
Class Participation on discussion (Question and answer)	100%	100%	100%	80%	80%	60%	60%	70%	80%	100%
Class participation on group activity (All members participate on activity)	80%	80% (1 group missing 2 members)	100%	80% (1 group missing 2 members)	60%	40% (1 group has 1 student)	60%	60%	80%	80%
Average activities score	79	85	84	77	69	56	64	71	82	84
Average quiz score			88			63			77	

From collected data in Table II, after applying gamification, the number of students that are absent is reduced due to teammates are encouraging the team member to attend the class to get the reward. By getting the learners attending the online class, it is also helping increase participation. More students eager to share and answer question to get a reward thus this also enable online discussion between the learners that lead to research the information to back up their answer. More learners are attending the activities and sharing creative ideas which lead to increasing in class average activities score and class average on quiz score. Through reward system, the learner with low level of self-directed learning will be encourage by teammate to join the class and participate in activities at first. After reward was granted and learner saw that their classmates got the prize, more of them have been motivated and tried to do the same.

However, this research is based on the traditional offline course that is transformed into online live teaching and applied gamification only one-third of the course. To recheck the effect, the gamification was applied to another Information Technology Project Management course in the following semester. This time the students will be learning by online live teaching from the first week. This means that student will never meet teacher in person before. So, the course content haves to attract the students to attend and participate in class from the beginning. The gamification has been applied to the course from the beginning to get the learner attention and motivate them to participate in class the result is shown in Table III.

Table III
Applying Gamification to Another Section
of Online Lives Teaching from the Beginning

Criteria	Traditional Offline Course			Online Live Teaching			Online Live Teaching with Gamification			
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Number of student absent (total 45 Students)	9	7	2	0	0	1	2	1	0	0
Class Participation on discussion (Question and answer)	60%	80%	100%	90%	100%	90%	90%	100%	100%	100%
Class participation on group activity (All members participate on activity)	60%	80%	100%	100%	100%	100%	90%	100%	100%	100%
Average activities score	69	73	78	80	79	82	87	88	92	90
Average quiz score			74			84			89	

From the data collected, the gamification can support in online learning by attracting the learner using concept of game and helps student s with low self-directed learning to attend and participate in class. By explain the game mechanic and system in the beginning of class, the learner is interested and eager to participate and follows the activities. At the beginning there are 9 students that missing from the class. By applied reward system, the second week the number of students absent is reduced and by the fourth week there are no students absent. Thus, class participation and group activities participation is keep going up. The students answer all the questions and participate in all discussions. This results in increasing the class average score on activities and quizzes. Then the research is extended further by removing reward on task the member assemble after the 6th week. This is to see the student behavior toward the class attendance without the reward. There are few students absent in the 7th week and 8th week to family matter and then there are no students absent in the last two weeks of the class. After discussion with all students in the class on the matter, the reason for participation including: at first when students heard that they have to study online, they feel that it is going to be complicated to use program to study. Another reason is that some of the students want to use class time for other activities such as playing game. The students confirmed that the reward system help draws their attention to attend the class. So, at first, they attend the class and gather member to get the reward. However, as the class progress and they are enjoying the class activities, they feel that the content is not complicated if they are attending the class and participating. So, after they realize that the reward is not necessary because they believe that by keeping attendance and participation, they can learn and do well on final exam. By linking the story with course content, this also motivates students to attend the class to see how the story goes and how to become successful project managers.

VI. Conclusion

From this research study gamification can help increase the level of self-directed learning by giving them the purpose that they will receive something in return. The reward system is motivating the students to attend the class, discussion, participation, etc. At the beginning the reward system is a must which acts as a digital engagement strategy to draw students to attend class. After they have attended the class several times, the barrier such as difficulty to study in live teaching online, communication, and knowledge sharing have been reduced. They feel like it is a common thing similar to traditional offline class and not afraid to attend or participate anymore. So, after that they feel the reward system is not necessary, it is good to have but not a must anymore. The students would like to participate and complete with other group in class activities to become successful project managersthrough gamification's experience design and goal achievement.

VII. Future Work

This research study focused mainly on applied gamification to support online live teachings. It can draw the attention and motivate the learner to attend and participate in class. Further development can be implemented on developing the course which currently the teacher gives live lecture online to become pure e-Learning that the learner can study by themselves. With the game mechanic applied to the course content to make learning by playing a game. The learner can learn on their own or as a group which can be supported and completed with each other based on game task. The teacher will become the moderator which can support, give a guideline for the student to complete the task. Moreover, the game mechanic should also applied on the quiz and final exam in order to utilize game mechanic thoroughly.

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Bullwhip Effect Prediction in a Single Echelon Supply Chain Using Regression Analysis

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***Abstract*—One of the main problems in supply chain systems is the bullwhip effect that can generate a huge cost for the companies in a chain. In this study, the factors and their impacts that can cause the bullwhip effect (order variance and net stock amplification) are investigated by using a simulation-based optimization approach. The proposed meta-prediction model is built using regression analysis, to predict the Total Stage Variance Ratio (TSVR) of the system. A single-echelon supply chain with uncertain customer demand operating under the periodic-review reorder cycle policy is studied. The parameters of the smoothing inventory replenishment and forecasting methods are required to search for their optimality in reducing the TSVR by OptQuest, an optimization tool in ARENA simulation software. Our results can assistdecision makers in the management of a supply chain, to realize, benchmark, and reduce the TSVR under an uncertain environment.**

***Index Terms*—Bullwhip Effect, Exponential Smoothing, Simulation-based Optimization, Meta-prediction Model, Regression Analysis**

I. Introduction

A supply chain is a combined system or networking for suppliers, manufactures, and retailers that is used until the products are in the hands of end customers. It aims to distribute the right product, at the right quantity and quality, at the right time to get the lowest cost [1]. A well-managed supply chain can play a large role in companies' logistics operations and the properties of the members in a chain. High attention must be paid in the logistics processes since better logistics processes could bring about better customer services [2]. However, the bullwhip effect can happen in a supply chain when orders, delivered to the manufacturers or suppliers, generate larger variance than the sales to the end customers. This order variance amplification is known as the bullwhip effect.

Inventory replenishment is a logistics process to transport the inventory from an upstream echelon to a downstream echelon. There are two types of inventory replenishment of interest: the reorder level policy and the reorder cycle policy. The difference is when and how many order quantities can satisfy the customer demand. The reorder level policy orders when the inventory level shrinks to the minimum reorder level point and the order quantity is set to be equal to the Economic Order Quantity (EOQ) (every time). In contrast, the reorder cycle policy defines a pre-determined "reorder cycle period". The difference between the on-hand stock at the review period and the maximum target stock level can be determined as the actual order quantity.

This study focuses on the replenishment by the Reorder Cycle Policy (ROC). With the ROC policy, the system is tracking the inventory position. The inventory position is reviewed periodically (daily, weekly, or monthly) and the order is fulfilled to the inventory position, up to the target stock level that determines order quantities [3]. When calculating the target stock level, the variation of the expected customer demand from the forecasting method is a key parameter, to control the variance in the supply chain system. Both the demand forecasting method and inventory replenishment policies are shown to contribute to the order variance and net stock variance problems.

Traditionally, the performance in a supply chain is evaluated by the order variance and the inventory variance. More researchers have studied the order variance ratio as the performance measure than the inventory variance ratio but our study combines both of them into one objective function called the "Total Stage Variance Ratio" (TSVR). Similarly, the studies of Wang and Shalaby [4] and Costantino et al. [5] also used the TSVRs to determine the overall performance of a supply chain. The order variance ratio increases the cost at the upstream echelon while the inventory variance ratio increases the holding and shortage costs. Hence, it is worthwhile to determine the TSVR, considering both factors as equally important at each echelon [6]. By minimizing the TSVR, the overall performance is improved in a supply chain.

In this study, the simulation-based optimization model is run to minimize the TSVR by OptQuest so that all smoothing parameters of the replenishment inventory policy and the forecasting method are searched for their optimal settings. Based on the results, the meta-prediction model can be used to determine the best level of the TSVR for a single-echelon chain under the ROC policy with the exponential smoothing forecasting technique under fluctuating lead time and end-customer demand. The major contribution of this study is to assist decision makers in predicting and realizing the amount of the bullwhip effect. They can then prepare and benchmark their supply chain system's performance to our optimal results, obtained from the meta-prediction model. The ordering quantity in each review period is searched for its optimality by adjusting two proportional controllers. Thus, a proper alleviation plan to reduce such effects can be made.

II. Literature Review

Only relevant research that is related to the bullwhip effect and inventory amplification problems are reviewed in this section

A. Bullwhip effect

The bullwhip effect has been measured by several models such as the statistical model [7], and [8], control theoretical model [3], [9], and [10], and simulation model [8], [11], and [12]. Chen et al. [7] studied the bullwhip effect of a two-stage supply chain using the statistical model. They considered only a retailer and a manufacturer. Their model applied two main factors (forecasting and lead time) to create the bullwhip effect. They concluded that the centralizing demand information can reduce the bullwhip effect but it cannot be eliminated.

B. Inventory Replenishment

Inventory replenishment policies are one of the major foundations of the bullwhip effect, in terms of variance amplification of stocking inventory in a supply chain. A majority of researchers in inventory replenishment have used the Reorder Cycle (ROC) policy [3]. The quantity to order in the ROC policy updates in every review period to fulfill inventories between the target stock level and inventory on hand. Disney and Lambrecht [6] explored variance amplification based on the ROC policy using different forecasting methods, including various operational conditions.

Dejonckheere et al. [9] also identified the smoothing replenishment of the reorder cycle policy by adding proportional controllers to the net stock term and the WIP term to satisfy the demand changes. This smoothing replenishment also decreases the bullwhip effect in the studies of [12], [13], and [14].

B. Demand forecasting methods

Demand forecasting is another factor causing the bullwhip effect [15] and [16]. Lee et al. [17] showed that both forecasting techniques (i.e., moving average and exponential smoothing method) always create demand variance amplification (bullwhip effect). An appropriate forecasting method can help reduce the bullwhip effect by minimizing the mean-square-error [15] and [18].

C. Simulation-based optimizations

Optimization is defined as the process of searching for the conditions that give the optimal value of a function, where the function indicates the efforts in that situation or environment. It is the act of gathering the best result under particular circumstances. There are two kinds of optimization algorithms to solve optimization problems: (1) the simplex algorithm that is usually used for the linear programming model, and (2) simulation based-optimization with heuristic algorithms, which is used to solve the problems in a reasonable time and where the problems are too complex (containing uncertainty or are too big to handle with the mathematical model as in the case of our studied model). Mazzuco et al. [19] applied simulation-based optimization with Simulated Annealing (SA) to the Vehicle Routing Problem (VRP) to find the optimal path that gives the minimum cost and delivery time. In their study, the OptQuest optimization tool was used to find the optimal parameter settings in a single-echelon supply chain model.

OptQuest is a powerful heuristic algorithm that is used in simulations. The OptQuest algorithm combines three metaheuristics, including scatter search, tabu search, and a neural network [20], and [21]. Bulut [22] used scatter search with OptQuest to solve the multi-scenario optimization problem on a large scale with the linear programming model.

III. Modeling Methodology

A. Supply chain model

The supply chain model in this study considers a single-echelon chain with the amount of end-customer demand following the normal distribution. A generalized periodic review with the Reorder Cycle (ROC) Policy inventory replenishment is used with two smoothing controllers under the exponential smoothing forecasting method. In practice, this is a case of a small supply chain where the retailers normally have higher bargaining power over the manufacturers due to the fact that they are closer to the end customers. As a result, they can control manufacturers' operations and be assured the availability of their supplies.

1) Single-echelon supply chain model

The retailer forecasts the expected demand and updates the target stock level in each period. Then, the retailer receives ordered products from the upstream echelon (i.e., manufacturer or supplier), and the actual demand (D_1) is monitored and satisfied. Next, the retailer monitors and updates its stock (inventory position) and finally places an order (O_t) to the upstream echelon at the end of each review period. The number of orders is determined, to fill back to the Replenishment ROC level (Target stock level). A single echelon supply chain model is considered with only one retailer and one manufacturer. It is assumed that the manufacturer can assure and distribute unlimited ordered quantities as addressed by the retailer. This single echelon model is shown in Fig. 1.

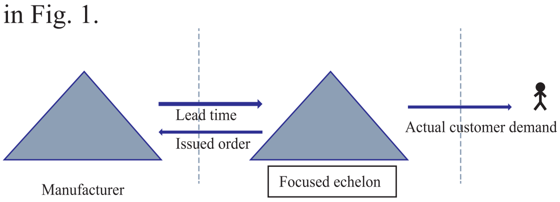

Fig. 1. Single-echelon supply chain model

2) Reorder Cycle policy (ROC)

The classical ROC policy can operate as follows. At the end of each Review period (R), an Order(O_t) is issued to the upstream echelon if the amount of the Inventory Position (IP_t) is less than the target stock level (S_t). The inventory position is reviewed at the end of every period, and an order is placed to raise the inventory position to the target stock level. The Inventory Position (IP_t) is equal to the stock-on-hand plus the inventory on order, minus the amount of the backlog (Net stock + inventory on order). The target stock level (S_t) is determined by (1).

$$S_t = (L_d + R + K)(\widehat{D}_t) \tag{1}$$

where

t = Time period
S_t = Target stock level
L_d = Lead time
R = Review period
K = Safety stock parameter
$\widehat{D}_t$ = Expected demand in period t

According to [9], the classical ROC policy with exponential smoothing or moving average always generates the bullwhip effect for any demand process. Therefore, as the process of demand is Independent and Identically Distributed (I.I.D), the best possible forecast process is the simple average of all previous demands. As a result, the order quantity can be written as (2).

$$O_t = Max\{(S_t - IP_t), 0\} \tag{2}$$

where

O_t = Order quantity in period t
IP_t = Inventory position in period t

From Equation (2), the inventory position is equal to the Net Stock (NS_t) plus the inventory on order (WIP_t). The net stock is equal to the difference between the Stock-On-Hand (SOH_t) and the backlog as shown in (3).

$$NS_t = SOH_t - Backlog_t \tag{3}$$

where

NS_t = Net stock in period t
SOH_t = Amount of stock on-hand in period t after clearing the backlog from period t (if any)
$Backlog_t$ = Amount of backlog in period t as SOH_t equal to 0

$$O_t = \widehat{D}_t(L_d + R) + K\widehat{D}_t - (NS_t + WIP_t) \tag{4}$$

$$O_t = R\widehat{D}_t + [L_d\widehat{D}_t - WIP_t] + [K\widehat{D}_t - NS_t] \tag{5}$$

In Equation (4), the order quatntity in each cycle is equal to the gap between the target stock level of that cycle minus the inventory position in that cycle. Equations (4) and (5) can be rearranged into three terms, which are the forecast term, the inventory discrepancy term, and the WIP discrepancy term. Therefore, the smoothing replenishment rule is applied to the order policies, in which the whole shortfall between the target stock level (S_t) and the available inventory may not be regained in each review period. As a result, only a fraction of the *NS* discrepancy and *WIP* discrepancy in each period is recovered. To implement smoothing replenishment patterns and adjust the amount of the gaps, an appropriate weight (T_n and T_w) is given to the gap term, as shown in (6)

$$O_t = R\widehat{D}_t + [L_d\widehat{D}_t - WIP_t]/T_w + [K\widehat{D}_t - NS_t]/T_n \tag{6}$$

where

WIP_t = Work in process in period t
T_w = Proportional controller for work in process discrepancy
T_n = Proportional controller for net stock

In Equation (6), two decision variables, T_w and T_n, are added as proportional controllers. This allows us to alter the dynamic behavior of the supply chain and decide the optimal ordering quantity in each period. These decision variables are used as simple amplifiers and are the most common controllers in control systems. By changing both of the proportional controllers, a set of ordering patterns, ranging from order variance amplification (bullwhip) to dampening (smoothing), are created.

B. Forecasting method

The forecasting method is introduced to calculate the expected demand for the next period at the end of each period. In this study, as the end-customer demand has no seasonality and trend (normally distributed), Exponential Smoothing (*ES*) is used to forecast the expected demand.

Exponential Smoothing method (ES)

As ES can only be used to make a one-period ahead forecast, Equation (7) shows the calculation of expected demand.

$$\widehat{D}_t = \alpha D_{t-1} + (1+\alpha)\widehat{D}_{t-1} \quad (7)$$

where

$\widehat{D}_t$ = Expected demand in period *t*

$\widehat{D}_t$ = Real demand in period *t*

α = Smoothing parameter

From Equation (7), α represents a parameter for ES that gives the weight between the recent demand observation (D_{t-1}) and historical forecasted demand ($\widehat{D}_{t-1}$).

C. Performance measure: Total Stage Variance Ratio (TSVR)

The efficiency of a supply chain can be measured by comparing the Total Stage Variance Ratio (TSVR) that can be calculated by the sum of the Order Variance Ratio (OVR) and Net Stock Amplification (NSA) [6], and [23]. This method assumes that the holding inventory cost is linearly close to the NSA and the production cost from inconsistent schedules is related to the OVR. It is also assumed that the costs of the OVR and NSA are equal so that the objective function minimizes the TSVR as shown in (8). Equations (9) and (10) represent the ratios of the order rate variance and net stock variance to the demand variance.

TSVR = OVR + NSA (8)

OVR = Order rate variance/Demand variance (9)

NSA = Net stock variance/Demand variance (10)

D. Simulation-based optimization with OptQuest

In this study, the ARENA simulation program is used to simulate the supply chain network. ARENA has an optimization tool called ‘OptQuest’. The objective function minimizes the TSVR under various factors that might create the bullwhip effect and net stock amplification.

Simulation model

The initial net stock (period 0) is assumed to be equal to the Target Stock Level (S_0) to avoid any backlog during the initial state. In every period, the process starts by (1) picking up the required items from stock following the actual end-customer demand when the amount of stock is higher than the amount of demand. However, if the amount of stock is less than the amount of demand, all stock is picked up and any demand shortage is considered to be a backlog, (2) a demand ($\widehat{D}_t$) is forecasted based on the used forecasting method and the target stock level (St) is updated, (3) the order quantity (O_t) is then calculated. If the net stock is less than the target stock level, the order is issued to the upstream echelon. Flowcharts of these supply chain operations are presented in Fig. 2 and Fig. 3.

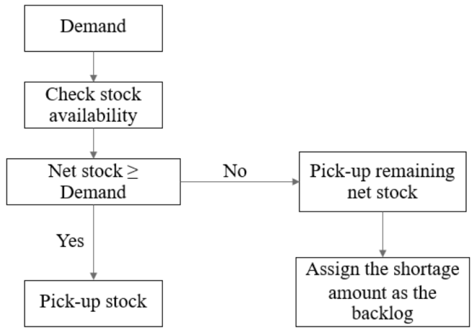

Fig. 2. Customer buying processes

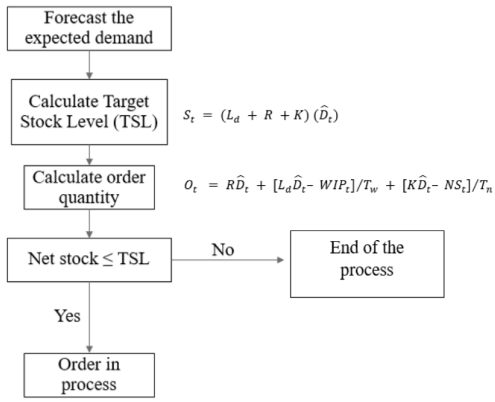

Fig. 3. Retailer ordering processes

E. Experimental condition

All experimental models are simulated and optimized with one decision variable, which is a smoothing decision variable of the forecasting methods. Then, two more decision variables from the order replenishment policy, which are T_n and T_w (proportional controllers), are added to the model to smooth the replenishment pattern and reduce the bullwhip effect. Operating parameters of the base case model are imposed with a Review period (R)= 1 period, Lead time (L_d)= 2 periods, and Safety stock (K) =1. The actual customer demand is assumed to follow the normal distribution with a mean of 50 units and a standard deviation of 5 units.

The simulation model is run under the terminating condition for 10 replications with a replication length of 5,000 periods and a warm-up period of 1,000 periods. Based on the supply chain model with exponential smoothing, various levels of controllable variable values (T_n, T_w and α) were used to find the steady-state conditions. The plot in Fig. 4 of these responses with three levels of the TSVR shows a warm-up period of 1,000 periods. With 10 replications, results can be obtained to guarantee the variation of the TSVR to be less than 3% of its mean.

IV. Analysis of the Results

Our experiment is divided into 3 studies. The first study finds the significance of our factors of interest. Then, the second study explains the effects of varying each significant factor in relation to the base case model (i.e., Review period (R)= 1 period, Safety stock (K)= 1, and Lead time (L_d)= 2 periods). Finally, the third study builds a meta-prediction model to predict the bullwhip effect (including order variance and stock amplification (TSVR)) of a single-echelon supply chain under lead time and customer demand uncertainties.

A. First experiment: Full factorial design

The experiment uses the full factorial design to incorporate the four factors of interest (i.e., lead-time duration, lead-time variation, customer demand variation, and safety stock) that might generate the bullwhip effect in the chain. The full factorial design uses 16 runs from 2^4 (each factor has two levels), with and without the two proportional controllers for the replenishment rule, as shown in Table I. These two levels of each factor cover the lower and upper limits and set the bounds of the experiment. Results of ANOVA are shown in Fig. 5 to Fig. 7 presents a Pareto chart of the TSVR with two proportional controllers.

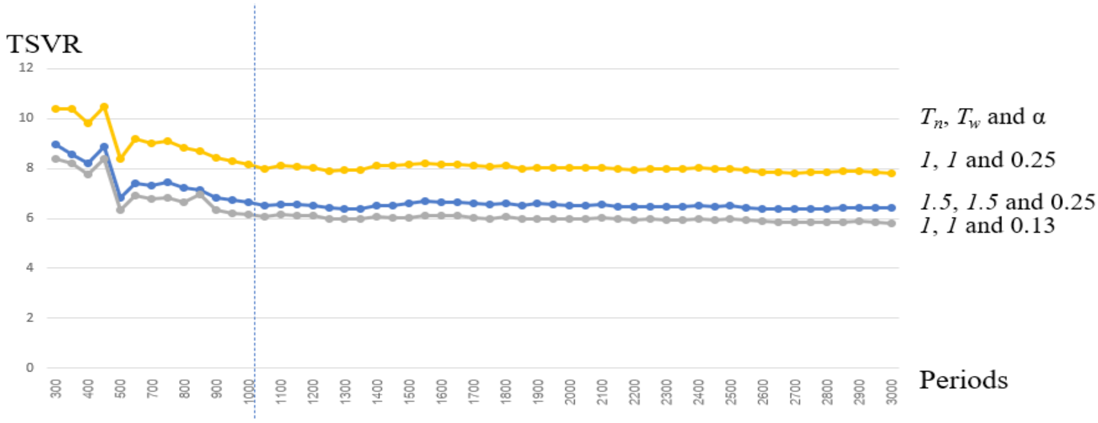

Fig. 4. Steady-state behavior of the TSVR

TABLE I
FULL FACTORIAL DESIGN OF FOUR FACTORS

Demand Variatioⁿ1	Lead time (period)	Lead-time Variation[2]	Safety stock	TSVR[3] without proportional controllers	TSVR[3] with two proportional controllers
0.1	2	0	1	3.08	2.65
0.1	2	0.5	1	169.28	70.60
0.1	4	0	1	5.40	5.00
0.1	4	0.5	1	332.14	151.53
0.3	2	0	1	3.10	2.74
0.3	2	0.5	1	21.62	11.14
0.3	4	0	1	5.39	5.05
0.3	4	0.5	1	42.13	21.72
0.1	2	0	4	3.08	2.70
0.1	2	0.5	4	172.00	57.86
0.1	4	0	4	5.48	4.83
0.1	4	0.5	4	379.08	113.42
0.3	2	0	4	3.04	2.65
0.3	2	0.5	4	21.58	9.29
0.3	4	0	4	5.12	4.73
0.3	4	0.5	4	47.53	18.10

Remarks: 1. Demand variation = Standard deviation of demand/mean of demand
2. Lead-time variation = Standard deviation of lead time/mean of lead time
3. TSVR = Average TSVR from 10 replications

Analysis of Variance (without two proportional controllers)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	15	2,205,957	147,064	530.02	0.000
Demand V	1	0	0	0.00	0.999
Lead time	1	5	5	0.02	0.889
Lead time V	1	74	74	0.27	0.607
Safety stock	1	0	0	0.00	0.994
Demand V*Lead time	1	0	0	0.00	0.996
Demand V*Lead time V	1	32	32	0.12	0.73
Demand V*Safety stock	1	0	0	0.00	0.992
Lead time*Lead time V	1	25,612	25,612	92.31	0.000
Lead time*Safety stock	1	0	0	0.00	0.989
Lead time V*Safety stock	1	190	190	0.68	0.409
Demand V*Lead time*Lead time V	1	12,194	12,194	43.95	0.000
Demand V*Lead time*Safety stock	1	0	0	0.00	0.985
Demand V*Lead time V*Safety stock	1	71	71	0.26	0.613
Lead time*Lead time V*Safety stock	1	616	616	2.22	0.138
Demand V*Lead time*Lead time V*Safety stock	1	242	242	0.87	0.352
Error	144	39,956	277		
Total	159	2,245,912			

Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
16.6574	98.22%	98.04%	97.85%

Demand V = End-customer demand variation
Lead time V = Lead-time variation
Lead time = Lead-time duration variation
Safety stock = Safety stock level

Fig. 5. Analysis of variance (without two proportional controllers)

Analysis of Variance (with two proportional controllers)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	15	306,525	2,0435.0	7,835.22	0.000
Demand V	1	0	0.0	0.01	0.933
lead time	1	6	6.4	2.45	0.120
lead time V	1	104	104.3	39.99	0.000
safety stock	1	0	0.1	0.02	0.887
Demand V*lead time	1	0	0.0	0.00	0.974
Demand V*lead time V	1	59	59.0	22.62	0.000
Demand V*safety stock	1	0	0.0	0.00	0.948
lead time*lead time V	1	8,409	8,409.2	3,224.26	0.00
lead time*safety stock	1	0	0.1	0.02	0.886
lead time V*safety stock	1	69	69.3	26.58	0.000
Demand V*lead time*lead time V	1	4,043	4043.1	1,550.21	0.000
Demand V*lead time*safety stock	1	0	0.0	0.00	0.999
Demand V*lead time V*safety stock	1	39	39.4	15.11	0.000
lead time*lead time V*safety stock	1	682	682.0	261.49	0.000
Demand V*lead time*lead time V*safety stock	1	348	347.9	133.38	0.000
Error	144	376	2.6		
Total	159	306,901			

Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
1.61496	99.88%	99.86%	99.85%

Demand V = End-customer demand variation
Lead time V = Lead-time variation
Lead time = Lead-time duration variation
Safety stock = Safety stock level

Fig. 6. Analysis of variance (with two proportional controllers)

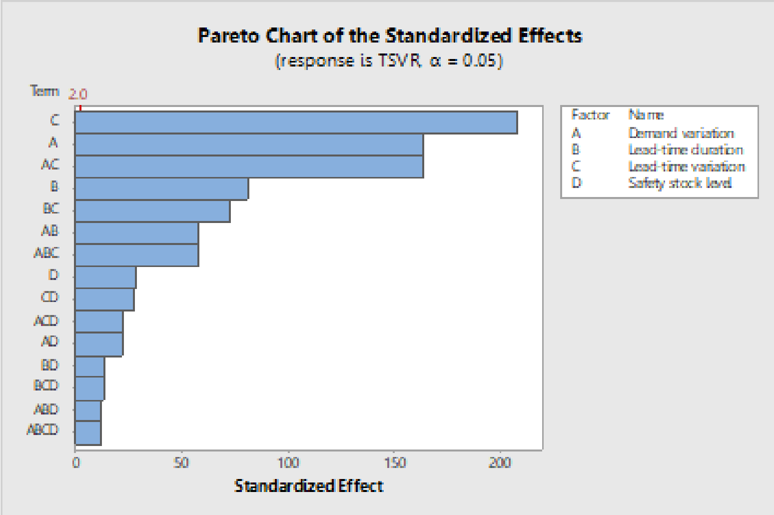

Fig. 7. Full factorial analysis under the 95% confidence level

According to Fig. 5 to 7, all main factors have a significant effect on the TSVR under the 95% confidence level, judging from the p-value. In addition, it is found that the lead-time variation has the most significant effect on the TSVR. Even though some main factors do not have a significant effect on the TSVR, their interactions have a significant effect. As a result, all factors of interest have a significant effect on the TSVR. Two proportional controllers for the replenishment rule are used to decide the best ordering quantity in each period. This significantly helps to reduce the effects of order variance and net stock amplification (see Table I for comparison). This allows us to alter the dynamic behavior of the supply chain and decide the optimal ordering quantity in each period.

B. Second experiment: Explanation of the effects of varying each significant factor

1) Base case model

The base case model is simulated under the ROC policy with the exponential smoothing forecasting method. There are three operating parameters in the base case model (i.e., Review period (R)= 1 period, Safety stock(K)= 1, and Lead time (L_d)=2 periods). Also, there are three smoothing decision variables to be optimized in the model; T_n, T_w and α. The results from the simulation-based optimization with OptQuest for the base case model are shown in Table II.

TABLE II
RESULTS OF THE BASE CASE MODEL

Reorder cycle policy					
Exponential smoothing with the end-customer demand = Norm (50,5) units					
T_n	***Tw***	***A***	***OVR***	***NSA***	***TSVR***
1.64	1.65	0	0.432	2.211	2.645

According to Table II, the optimal value of α obtained from OptQuest is 0, meaning that the demand forecast is similar to the long-term average of the customer demand. Furthermore, the demand forecast is found to be constant in every period. Shaban and Shalaby [1] also reported an α value of 0 in their experiment under the same customer demand pattern with the normal distribution. They concluded that the demand forecast should be constant in every review period regardless of the variation of end-customer demand, providing that there are no seasonality and trend effects in the demand pattern. The Total Stage Variance Ratio (TSVR) of the base case model is equal to 2.645, which shows a high level of the bullwhip effect. In addition, the net stock amplification appears to cause more variance amplification than the order variance. This is because the order variance has T_w and T_n as proportional controllers, to alter the dynamic behavior as stated earlier.

2) Lead-time duration variation

In this experiment, the lead-time duration (L_d) is varied from 1, 2, 3, to 4 periods while other parameters are fixed. This is similar to the base case model at the R = 1 period, and K = 1 under the reorder cycle policy with the exponential smoothing forecasting method.

TABLE III
LEAD-TIME DURATION VARIATION

Reorder cycle policy						
Exponential smoothing with the end-customer demand = Norm (50,5) units						
Lead times	T_n	T_w	*α*	***OVR***	***NSA***	***TSVR***
1	1.59	1.61	0	0.484	1.227	1.711
2	1.64	1.65	0	0.432	2.211	2.645
3	1.49	1.49	0	0.507	3.148	3.656
4	1.63	1.64	0	0.520	4.483	5.003

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Factor   N     Mean  Grouping
SD 20   10  2.91378  A
SD 15   10  2.73422    B
SD 10   10  2.64578      C
SD 5    10  2.63676      C

Means that do not share a letter are significantly different.
```

Fig. 8. Lead-time duration variation using the Tukey comparison test under the 95% confidence level

The results from the simulation-based optimization with OptQuest in each level of lead-time duration are shown in Table III. The lead time has an impact on the TSVR since there is a significant difference among the four different levels of the lead time under the 95% confidence level using the Tukey comparison test as shown in Fig. 8. When the lead-time duration is longer, the TSVR is also higher, mainly caused by the net stock amplification. While increasing the lead-time duration, a higher variance is mainly caused by the net stock term. After increasing the lead time, the net stock amplification becomes higher as a result of the end-customer demand fluctuation. The Order Variance Ratio (OVR) is stable throughout all levels of the lead time since the number of orders in each cycle is stable under the same pattern of end-customer demand due to the smoothing replenishment with two proportional controllers.

3) Lead-time variation

In this experiment, the lead-time duration (L_d) follows the normal distribution with the mean varying from 1 to 3 periods. The standard deviation at each mean level is varied into 2 levels (i.e., 50 and 100 percent of its mean) while other parameters are fixed at R = 1 period, and K = 1, similar to the base case model under the recycle order policy with the exponential smoothing forecasting method. Tables IV and V show the results from simulation-based optimization with OptQuest with lead-time variation.

The results from Tables IV and V show that the lead-time variation causes a huge TSVR in the supply chain system. The variance comes from the amplification of the net stock rather than the order variance due to the severe stock shortage and backlog. As the lead-time variation increases, the TSL (calculated from equation (1)) also varies and fluctuates in each period, causing a huge amplification in the net stock.

TABLE IV
LEAD-TIME VARIATION WITH STANDARD DEVIATION EQUAL TO 50% OF ITS MEAN

Reorder cycle policy						
Exponential smoothing with the end-customer demand = Norm (50,5) units						
Lead time (period)	T_n	*Tw*	α	*OVR*	*NSA*	*TSVR*
norm (1,0.5)	5.91	3.70	0.01	3.58	26.79	30.37
norm (2,1)	5.30	4.83	0.01	7.49	63.17	70.67
norm (3,1.5)	12.38	7.66	0.00	10.13	99.62	109.75

TABLE V
LEAD-TIME VARIATION WITH STANDARD DEVIATION EQUAL TO 100% OF ITS MEAN

Reorder cycle policy						
Exponential smoothing with the end-customer demand = Norm (50,5) units						
Lead time (period)	T_n	*Tw*	α	*OVR*	*NSA*	*TSVR*
norm (1,1)	9.01	4.26	0	9.01	55.41	64.42
norm (2,2)	7.83	7.38	0	16.70	116.71	133.41
norm (3,3)	748.1	10.72	0	21.99	175.92	198.01

4) End-customer demand variation

In this experiment, the end-customer demand follows the normal distribution with the mean fixed at 50 units but the standard deviation is varied with 4 levels (i.e., 10%, 20%, 30% and 40% of the mean). Other parameters are set similar to the base case model where the Review period (R) = 1 period, Safety stock (k) = 1, and Lead time (L_d) = 2 periods under the exponential smoothing forecasting method with the reorder cycle policy. The obtained optimal values of the TSVR from OptQuest of the four levels of standard deviation are shown in Table VI.

TABLE VI
END-CUSTOMER DEMAND VARIATION

Reorder cycle policy						
Exponential smoothing with the end-customer demand = Norm (50,5) units						
S.D. of end-customer demand	T_n	T_w	α	***OVR***	***NSA***	***TSVR***
10% of the mean	1.64	1.65	0	0.43	2.21	2.64
20% of the mean	1.40	1.40	0	0.55	2.10	2.65
30% of the mean	1.67	1.67	0	0.44	2.29	2.73
40% of the mean	1.44	1.41	0	0.55	2.36	2.91

Fig. 9. Tukey comparison test of four levels of the end-customer demand following the normal distribution with the mean equal to 50 units under the 95% confidence level

From Table VI and Fig. 9, it was found that increasing the variation of the end-customer demand can cause a certain bullwhip effect, in terms of the TSVR. However, the severity is worsened with a higher level of the demand variation from its standard deviation of 30% or higher (as indicated by the Tukey comparison test). Most of the effect comes from the net stock as the order variance is stable despite increasing the demand variation.

5) Safety stock level

The main parameters from the base case model are fixed except the safety-stock (K), which is varied from K=1 to 4. The results from the simulation-based optimization with OptQuest while varying the value of K are shown in Table VII. The Tukey comparison test is presented in Fig. 10, showing that varying only the level of the safety stock does not have a significant effect on the TSVR. This result is in the same direction as the result obtained from the analysis of variance in the first experiment, in which the safety stock level alone does not have a significant effect on the TSVR. However, its interaction with the lead-time variation has a significant effect on the TSVR.

TABLE VII
SAFETY STOCK VARIATION

Reorder cycle policy						
Exponential smoothing with the end-customer demand = Norm (50,5) units						
Safety stock (*K*)	T_n	*Tw*	α	***OVR***	***NSA***	***TSVR***
1	1.64	1.65	0	0.432	2.211	2.645
2	1.48	1.48	0	0.507	2.134	2.641
3	1.47	1.47	0	0.515	2.136	2.652
4	1.46	1.46	0	0.525	2.132	2.657

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence

Factor   N    Mean  Grouping
K 4     10  2.6569  A
K 3     10  2.6518  A
K 2     10  2.6416  A
K 1     10  2.6456  A

Means that do not share a letter are significantly different.
```

Fig. 10. Tukey comparison test of the safety stock level under the 95% confidence level

C. Third experiment: Meta-prediction model

A meta-prediction model was designed to predict the performance (TSVR) under a single-echelon supply chain with the ROC policy using the exponential smoothing forecasting method with and without the proportional controllers. The main purpose of this study is to assess the impact of the factors of interest on the severity of the bullwhip effect, in terms of the Total Stage Variance Ratio (TSVR). The independent variables include the lead-time duration, the standard deviation of lead time, the standard deviation of customer demand, and the level of safety stock. From the ANOVA results (Fig. 5 and 6), a multiple regression model can be built based on these 4 independent factors.

The behavior of these independent variables has a statistically significant effect on the TSVR, except for some interaction terms. However, some 3-way or 4-way interaction terms covering all main factors have a significant effect on the TSVR judged by a *p*-value of less than 0.05. Both R^2 (Adjusted) of the model with and without the proportional controllers indicate that both regression models can explain the TSVRs. This was also guaranteed by the lack-of-fit test, in which there is not enough evidence to state that the model has a "lack of fit" since the *p*-value is greater than 0.05, meaning that the prediction model is significant. Subsequently, the regression equation can be obtained.

Regression equation without two proportional controllers (replenishment policy):

TSVR = 0.8 - 0.1 Demand variation + 1.13 Lead-time duration
+ 37.4 Lead-time variation - 0.06 Safety stock level
+ 0.2 Demand variation*Lead-time duration
- 110 Demand variation*Lead-time variation
+ 0.4 Demand variation*Safety stock level

+ 220.0 Lead-time duration*Lead-time variation
+ 0.04 Lead-time duration*Safety stock level
- 20.7 Lead-time variation*Safety stock level
- 678.8 Demand variation*Lead-time duration*Lead-time variation
- 0.24 Demand variation*Lead-time duration*Safety stock level
+ 56.6 Demand variation*Lead-time variation*Safety stock level
+ 11.71 Lead-time duration*Lead-time variation*Safety stock level
- 32.8 Demand variation*Lead-time duration*Lead-time variation*Safety stock level

Regression equation with two proportional controllers (replenishment policy):

TSVR = 0.1 + 0.9 Demand variation
+ 1.23 Lead-time duration
- 44.4 Lead-time variation
+ 0.12 Safety stock level
- 0.1 Demand variation*Lead-time duration
+ 149 Demand variation*Leadtime variation
- 0.2 Demand variation*Safety stock level
+ 126.0 Lead-time duration*Lead-time variation
- 0.04 Lead-time duration*Safety stock level
+ 12.4 Lead-time variation*Safety stock level
- 390.8 Demand variation*Lead-time duration*Lead-time variation
+ 0.00 Demand variation*Lead-time duration*Safety stock level
- 41.8 Demand variation*Lead-time variation*Safety stock level
- 12.31 Lead-time duration*Lead-time variation*Safety stock level
+ 39.3 Demand variation*Lead-time duration*Lead-time variation*Safety stock level

Measure of accuracy by Mean Absolute Percentage Error (MAPE)

The MAPE is used to indicate the accuracy of the meta-prediction model as shown in (11).

$$\text{MAPE} = \frac{\sum \frac{|Actual - predicted|}{Actual}}{n} \tag{11}$$

The MAPE is expressed in terms of a percentage value. It is used to compare the error between the actual outcome and the outcome from the meta-prediction model. The lower the MAPE value, the better the accuracy of the prediction model. Lewis [24] proposed that if the value of the MAPE is from 10 to 20%, the model generates a good prediction. If the value of the MAPE is from 20 to 50%, the model is considered to be a reasonable predicting model. However, if it is more than 50%, the model cannot be used to predict any results.

Tables VIII and IX report the results in terms of the accuracy of the prediction model. The results are compared between the actual TSVR from the simulation model and the estimated TSVR from the meta-prediction model. We use similar input data within the boundary of the problem (Lead time = 1 to 4 periods, Lead-time variation from 0 to 50 percent of its mean, Demand variability from 0 to 40 percent of its mean, Safety stock (K) = 1 to 4). The results for similar input data within the boundary of the problem with proportional controllers show that the average MAPE is 1.84%. However, the results for different input data (but within the boundary of the problem) are slightly higher at 3.65%. Both MAPE values from these two tests are less than 5%, meaning that the meta-prediction model from the regression analysis is sufficiently accurate to predict the TSVR under a single-echelon supply chain operating with the ROC policy.

TABLE VIII
MAPE WITH SIMILAR INPUT DATA WITHIN THE BOUNDARY

MAPE with similar input data					
Demand Variation	**Lead time (period)**	**Lead-time variation**	**Safety stock**	**TSVR (predicted)**	**MAPE**
0.1	2	0	1	2.64	1.4
0.1	2	0.5	1	70.59	1.81
0.1	4	0	1	5.00	2.01
0.1	4	0.5	1	151.53	2.49
0.3	2	0	1	2.74	1.45
0.3	2	0.5	1	11.14	1.94
0.3	4	0	1	5.05	1.9
0.3	4	0.5	1	21.72	2.16
0.1	2	0	4	2.70	1.25

TABLE VIII
MAPE WITH SIMILAR INPUT DATA WITHIN THE BOUNDARY (CONT.)

MAPE with similar input data					
Demand Variation	**Lead time (period)**	**Lead-time variation**	**Safety stock**	**TSVR (predicted)**	**MAPE**
0.1	2	0.5	4	57.86	1.27
0.1	4	0	4	4.83	1.9
0.1	4	0.5	4	113.42	2.24
0.3	2	0	4	2.65	1.73
0.3	2	0.5	4	9.29	1.73
0.3	4	0	4	4.73	1.94
0.3	4	0.5	4	18.10	2.24
				AVERAGE	1.84

TABLE IX
MAPE WITH DIFFERENT INPUT DATA WITHIN THE BOUNDARY

MAPE with different input					
Demand Variation	**Lead time (period)**	**Lead-time variation**	**Safety stock**	**TSVR (Predicted)**	**MAPE**
0.2	2	0	1	2.69	1.57
0.15	2	0	1	2.67	2.64
0.1	3	0	1	3.82	4.57
0.1	2	0	2	2.66	0.6
0.1	2	0	3	2.68	3.36
0.1	3	0.5	1	111.07	3.65
0.25	2	0	1	2.71	1.97
0.1	2	0	3.5	2.69	3.99
0.15	2	0	2	2.67	0.95
				AVERAGE	2.25

For instance, to predict the TSVR with two proportional controllers when the Safety stock (K) = 1, Lead time (L_d) = 2 periods, Lead-time variability = 50 percent of its mean, and Demand variability = 10 percent of its mean:

TSVR = 0.1 + 0.9*0.1 + 1.229*2 - 44.39*0.5+0.121*1
- 0.11*0.1*2+149.3*0.1*0.5-0.25*0.1*1
+ 126.03*2*0.5-0.039*2*1
+ 12.41*0.5*1-390.82*0.1*2*0.5
- 41.8*0.1*0.5*1
- 12.311*2*0.5*1
+ 39.32*0.1*2*0.5*1

As a result, TSVR = 70.59 as compared to TSVRs ranging from 68.405 to 74.711 from ten replications that were obtained from the simulation model running with the above-mentioned parameters. This prediction obtains a MAPE of 1.81%. Such a prediction model would help decision makers to be aware of the amount of the bullwhip effect in advance. This information would be of value to the decision makers for managing and benchmarking their supply chain operations, with or without the optimal ordering quantity. They can use the obtained information for deciding their operating conditions in their chains by realizing when each factor may need to be varied (and its effects), such as reducing the lead time or increasing the level of safety stock.

V. CONCLUSION

The bullwhip effect commonly occurs in a supply chain operating under uncertainties. This study examined four factors, which can generate the bullwhip in terms of order variance and net stock amplification: lead-time duration, lead-time variability, customer demand variability, and safety stock level. The performance of a supply chain is determined by the summation of the order variance and the net stock amplification (TSVR). The simulation-based optimization was applied in this study to find the optimal level of required parameters to minimize the bullwhip effect. A single-echelon supply chain model was simulated and optimized by ARENA software with the OptQuest optimization tool. Also, this study proposed the meta-prediction model based on regression analysis, to predict the total amplification.

This single-echelon supply chain operates with end-customer demand following the normal distribution under the Reorder Cycle (ROC) replenishment policy with the exponential smoothing forecasting technique. To compare the performances of each experiment, the Tukey comparison test is used at the 95 % confidence level. The results showed that all factors of interest, including the lead-time duration, lead-time variability, safety stock level, and end-customer demand variability, are significant, causing the bullwhip effect and net stock amplification. The lead-time variation has the highest significant effect on the severity of the TSVR. Two proportional controllers can alter the dynamic behavior of the supply chain system. They help to smooth the replenishment pattern by giving the optimal ordering quantity in each review period, and they significantly help to reduce the bullwhip effect and net stock amplification. In addition, the results obtained from the prediction model are accurate, giving a MAPE value of less than 3% for similar input data and less than 5% for different input data within the boundary of interest. Our findings would be of value to decision makers to realize, prepare, and benchmark the effects from uncontrollable uncertainties so that a proper alleviation plan can be made in advance.

Our study considered only one type of inventory ordering policy (i.e., the reorder cycle policy), which can be further explored with other types of inventory replenishment policies such as the reorder level policy, etc. In addition, our model was simulated only with a single-echelon supply chain. A further study can be extended to a multi-echelon supply chain with centralized or decentralized ordering policies (with or without information sharing). A combination of these policies can be studied for their roles in the bullwhip effect and net stock amplification. This could be a major research area that is worth exploring.

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Factors Influencing the Microstructure and Corrosion Resistance of Austenitic and Duplex Stainless Steel Castings

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***Abstract*—The demand for Austenitic and Duplex Stainless Steel Castings has increased with investment in the petrochemical industry, transportation infrastructure and electric vehicle production in Thailand. To achieve high quality casting of these two grades, alloying elements melt quality, pre and post-treatment of castings play an important role in quality level determination. These important factors are discussed along with guidelines for good manufacturing practices to achieve the required microstructures and high-quality castings from the domestic foundry sector in Thailand.**

***Index Terms*—Austenitic and Duplex Grades, Corrosion Resistance, Microstructure, Stainless Steels**

I. Introduction

The formation of air formed oxide films on the surface of metallic materials can offer some protection against subsequent attack by corrosive media. This is known as *"passivation"*. In stainless steels passivation is achieved by alloying with chromium which gives rise to a thin, self-repairing, protective layer of chromium-based oxide over the surface of the steel. For stainless behavior a minimum of 12% Cr is required in solid solution in the matrix of the steel. Even though protected by an oxide film stainless steel can still be prone to highly damaging localized forms of corrosion such as pitting, crevice and intergranular attack and not least stress corrosion cracking [1]. Additions of other alloying elements, notably Ni, Mo and N, are therefore also included in stainless steels in order to improve resistance to such local forms of corrosion and to control the matrix structure and mechanical properties. Stainless steels can be supplied in cast, wrought and powder metallurgy product forms. In all of these forms the composition, especially the carbon level, and the processing, welding, and heat treatment variables must be carefully controlled. Correct control ensures that the required distribution of alloying elements is obtained and that the formation of Cr rich carbides and other damaging second phases in the microstructure is minimized. The presence of carbides and second phases can not only cause severe pitting and intergranular attack due to micro-galvanic effects but can also reduce mechanical properties such as toughness.

A number of types of stainless steel have been developed including:

- Ferritic, containing 12 - 30 % Cr and very low C levels
- Martensitic with 12 - 17 % Cr and 0.1 - 1.0%C
- Austenitic containing 17 - 25% Cr with 8 - 12 % Ni + other alloy elements or 20 - 27% Cr with 20 - 35 % Ni
- Duplex alloys with 22 - 30 % Cr, 3 - 7% Ni + other alloy elements
- Precipitation hardening alloys which can have austenitic or martensitic matrices with additions of Cu, Ti, Al, Mo, Nb or N

There are many comprehensive reviews and guides [2]-[6] covering the compositions, physical metallurgy, properties, corrosion behavior and service performance of stainless steels. Much of these literatures focus on wrought grades with relatively little attention being given to casting grades. Compared to wrought grades, the grades for castings have modified compositions to improve fluidity during mould filling and to prevent hot cracking during solidification and cooling. Levels of residual elements may also be more variable due to the relatively smaller melt sizes used for castings production. The presence of typically coarser and less homogeneous microstructures in castings together with such compositional differences will result in some differences in mechanical properties and corrosion resistance between castings and wrought products [7]. Composition and property requirements for stainless steel castings are covered by a number of international, patent licence-holder and individual company standards. Never the less, it is common practice for many foundries and their customers in S.E. Asia to refer and produce to compositions from wrought grades such as AISI 316. To obtain suitable cast ability and to avoid problems with casting quality issues, foundries should produce to recognized casting standards, the most widely accepted of these are those issued by ASTM, e.g. A743/A743M and A744/A744M [8], [9]. The chemical compositions of some austenitic and duplex casting grades are listed in Table 1.

TABLE I
EXAMPLES OF MAIN ALLOY ELEMENTS USED IN CAST STAINLESS STEELS
(VALUES IN WT.%).
[DATA FROM 8.9.19.20,43]

Alloy (ACI form)	UNS	C (Max)	Cr	Ni	Mo	N	Other
1 - CF8	J92600	0.08	18.0-21.0	8.0-11.0	-	-	-
2 - CF8M	J92900	0.08	18.0-21.0	9.0-12.0	2.0-3.0	-	-
2 - CF3M	J92800	0.03	17.0-21.0	9.0-13.0	2.0-3.0	-	-
4 - CK3MCuN	J93254	0.025	19.5-20.5	17.5-19.5	6.0-7.0	0.18-0.24	0.5-1.0 Cu
5 – CD3MN	J92205	0.03	21.0-23.0	4.5-6.5	2.5-3.5	0.1-0.20	-
6 – CD4MCu	J93370	0.04	25-26.5	4.75-6.0	1.75-2.25	2.75-3,25	-
7 – CE8MN	J93345	0.08	22.5-25.5	8.0-11.0	3.0-4.5	0.1-0.3	-
8 – CD3MWCuN	J93380	0.03	24.0-26.0	6.5-8.5	3.0-4.0	0.2-0.3	0.5-1.0W, 0.5-1.0Cu

In Table I Steels 1-4 are austenitic grades, steels 5-8 are duplex grades, The grades are in the ACI form used in ASTM standards. For reference each equivalent UNS number is listed. CF8 and CF8M are the casting alloy equivalents to 304 and 316, CF3M is equivalent to 316L. The Mn level is normally <1.0% with Si<1.5%, S<0.04% and P<0.04%.

To satisfy local market demand for cast components such as valve or pump bodies and impellers Thai foundry companies have shown increasing interest in producing austenitic and duplex grades of stainless steel. This short article provides an outline of the important metallurgical factors that must be controlled when producing corrosion resistant castings in such grades. With reference to some microstructural observations emphasis is given to the relationships between composition, microstructure and corrosion resistance.

II. EFFECTS OF ALLOYING IN AUSTENITIC AND DUPLEX GRADES.

The basic effects of the main alloying elements can be outlined as [2]:

A. Chromium

This is the main element to give corrosion resistance by providing a stable, protective, self-healing oxide film on exposure to air or aqueous environments.

B. Nickel

This stabilizes austenite and improves general corrosion resistance in most environments which do not contain sulphides.

C. Molybdenum

Increases resistance to pitting and crevice corrosion resistance especially in aggressive environments containing chlorides and sulphur.

D. Nitrogen

Stabilizes and solid solution strengthens austenite and increases pitting resistance.

E. Copper

Improves general corrosion resistance and can act as a substitute austenite former in place of Ni.

As a result of steel making processes the common elements Mn, Si, S and P are all present. The Mn level is normally kept below 1.5% and Si below 1% in wrought grades and below 2% in casting grades. S and P have harmful effects on corrosion resistance and weldability and must be below 0.03 and 0.045% respectively to meet standards. Preferably S and P should be as low as possible. However, in some grades additions of S can be made to improve machinability. Higher additions of Mn in combination with 0.25% N addition have been used to reduce costs by substituting for Ni, for example at 6-7% Mn the Ni content can be reduced from 8-10% to 4-6%. This has resulted in the development of the 200 series wrought austenitic stainless grades as a cheaper alternative to AISI 304 [10].

In Austenitic Grades a stable austenitic matrix is obtained by the addition of at least 8% Ni to 18% Cr steels. Nickel increases the amount of austenite produced during solution heat treatment and also lowers the Ms (martensite start temperature) to sub-zero. The steels often contain additions of Mo, N, Nb, Ti and Cu to improve properties and remain essentially austenitic at all temperatures [2]. Some grades contain up to 20% delta ferrite to improve weldability [2], [11]. The interaction between Cr (which is a ferrite former) and Ni (which is an austenite former) and other alloying elements is most conveniently described by the use of Cr and Ni equivalents based on wt.% amounts of given alloy elements, for example:

$$\text{Chromium equivalent } Cr_e = (Cr) + 2(Si) + 1.5(Mo) + 5.5(Al) + 1.75(Nb) + 1.5(Ti) + 0.75\,(W) \quad (1)$$

$$\text{Nickel equivalent } Ni_e = (Ni) + (Co) + 0.5(Mn) + 0.3(Cu) + 25(N) + 30(C) \quad (2)$$

These equivalents, some based on different formulae, are used in the plotting of Schaeffer type diagrams as illustrated in Fig. 1, such diagrams [11]-[13] are used to predict weld microstructures, especially the proportion of ferrite, but can also provide a guide to expected as-cast structures in small sectioned castings in that they indicate the approximate areas of stability of the various microstructures in stainless steels. The presence of a controlled amount of primary delta ferrite minimizes hot cracking in welds [11].

Due to their FCC crystal structure austenitic grades are non-magnetic, relatively tough at low temperatures, and have useful creep resistance up to about 900°C. Their yield strengths are relatively low. Interstitial solid solution hardening is the most effective means of strengthening but C addition cannot be used since C encourages the precipitation of Cr carbides, which seriously reduce corrosion resistance. N, in additions normally up to 0.2% is therefore the main element used for solid solution strengthening.

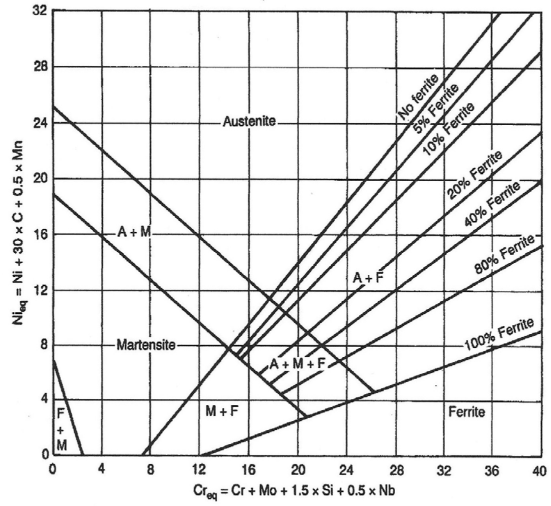

Fig. 1. Example of a Schaeffler-delong diagram using basic formulae for Ni and Cr equivalents [11]-[13]

Austenitic grades are susceptible to Stress Corrosion Cracking (SCC) when exposed to chloride containing environments [5]. SCC tends to occur in stainless steels and other alloys under a particular set of circumstances for a given alloy i.e. *particular alloy and condition, specific corrosive media, sufficient local tensile stress.* SCC is most likely nucleated at pitting damage sites and develops under the action of local tensile stresses as a highly branched network of intergranular or trans granular fine cracks depending on the nature of the alloy. SCC tendency is lower in ferritic and martensitic alloys. The presence of delta ferrite in austenitic steels is known to improve SCC resistance.

If slowly cooled through or held in the temperature range 450-850°C austenitic stainless steels can be sensitized by the formation of grain boundary Cr-rich carbides [14]. This can occur in heat affected zones during welding and in thicker sections of solution treated castings. The presence of such carbides can then lead to intergranular corrosion in service, as indicated schematically in Fig. 2 [15].

For austenitic steels to be welded without the precipitation of Cr carbides and the accompanying danger of subsequent intergranular attack additions of titanium *(%Ti = 5 x %C)* or niobium *(%Nb = 10 x %C)* are used. These additions result in precipitation of stable TiC or NbC carbides in heat affected zones. The carbon is therefore not free to form Cr carbides and the steel is said to be "stabilized". Chromium rich carbide precipitation can also be minimized by producing very low carbon steels, ideally containing below 0.02% C [2], [5].

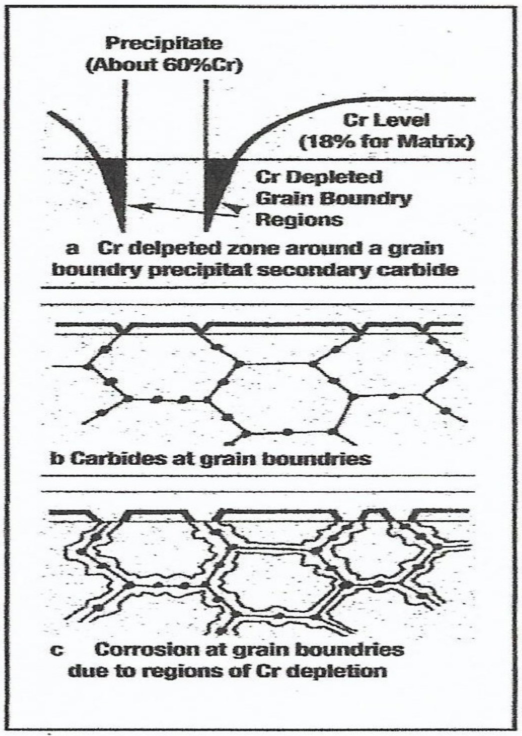

Fig. 2. Schematic view of intergranular attack caused by precipitation of Cr-rich carbides at grain boundaries in an austenitic stainless steel [1], [15].

The **Duplex** grades with mixed austenite and ferrite structures are designed to give greater SCC resistance than austenitic steels [4], [16], [17]. The duplex microstructure helps to inhibit crack growth by arresting or deflecting the cracks at the austenite/ferrite interfaces. Maximum SCC resistance appears to be obtained in 50-50 austenite-ferrite microstructures and ideally the dispersion of the two phases should be as fine as possible. To produce duplex grades the Cr content is raised to 20-25%, and Ni reduced to 4-7% with additional control of the levels of Mo and N. Duplex grades have higher yield (proof) strengths but lower toughness than the austenitic grades. Their 0.2% proof stress values range from 400 to 550 MPa compared to only 200 - 300 MPa for low N austenitic grades. Because austenite work hardens during plastic deformation the UTS values for the duplex and austenite grades are similar. The higher proof stress levels of duplex steels offer savings in material and weight over austenitic grades, and also allow castings to be designed with thinner, easier to feed sections. Although the Ni content of the duplex grades, at 4-8%, is lower than for conventional austenitic steels their pitting resistance, if correctly heat treated, is at least equivalent to that of the austenitic grades due to their higher Cr and Mo levels [2], [18].

Duplex stainless steels can be classified into four groups:

- Lean alloy Mo-free such as 23Cr-4Ni-0.1N.
- Standard 22%Cr SS of the type 22Cr-5Ni-3Mo-0.17N.
- High Alloy 25 Cr with Mo, N and Cu or W.
- Super-duplex e.g. 25 Cr-7Ni -3.5Mo-0.27N.

The use of duplex grades in various wrought product forms such as bar, tube and plate has been well established for a number of years. In recent years interest has grown in their use as castings especially for applications such as pump and valve bodies [18] since they can be used to provide greater resistance to corrosion in seawater and in sour gas applications where there may be contamination from hydrogen sulphide and ammonia. For applications in the oil, gas, and petroleum sector duplex grades are increasingly used in preference to austenitic especially in chloride or sulphide containing environments. The first ASTM standard specific to duplex stainless steel castings was issued in 1988 as ASTM A890 [19]. Later in 1998 to meet the requirements for pressure containment another standard, ASTM A995 [20], was issued setting down tighter requirements for compositional limits, traceability, tensile and pressure testing, weld repair and heat treatment, etc. A casting which satisfies A995 also satisfies A890.

Additions of Mo are made to both austenitic and duplex stainless steels to improve both general corrosion and pitting resistance with Mo contents of 4.5 to 7% giving rise to the so called *"Superstainless"* grades [4], [6], [21]-[24]. These alloys were initially developed to provide greater resistance to resist corrosion in sea water where it has been found that at least 3% Mo is needed in ferritic steels and at least 6% Mo in austenitic steels to avoid crevice corrosion attack. In both austenitic and duplex steels additions of N can give further improvements in pitting resistance [2]-[7].

The combined effects of alloying elements on corrosion resistance can be described by a *Pitting Resistance Equivalent Number PREN* calculated from composition such as:

$$PREN = \%\,Cr + 3.3\,(\%\,Mo) + X\,(\%\,N) \tag{3}$$

X = 16 for duplex and X = 30 for austenitic.

Several different formulae have been proposed for PREN including the contribution by W addition when present [22], [23], [25]-[27]. All are empirical relationships based upon laboratory corrosion tests in chloride containing solutions. Superstainless grades give PREN values of 40-45 compared to 20-25 for normal grades. Pitting resistance is measured in chloride containing environments since it is the chloride ion which is mainly responsible for localized damage to the passive oxide film. Pits tend to develop at microstructural features such as grain boundaries, second phase particles or inclusions (carbides, oxides, sulphides) and at delta ferrite/austenite interfaces in duplex structures. PREN values have become commonly used for general ranking of pitting resistance. For example, a PREN value of >40 is normally specified for seawater service [28].

Calculated PREN values do not always take into account the effect of other alloy additions such as Ni, Cu, Mn, etc., which must also have some influence on pitting behaviour. It must be recognized that using bulk composition as a basis for pitting resistance can be misleading when both austenite and ferrite phases are present in the microstructure as in duplex steels and austenitic grades containing ferrite. Elemental partitioning between austenite and ferrite determines the pitting resistance of each phase, hence the PREN value should relate to that of the phase with the lesser resistance [25]-[27] where possible composition and heat treatment conditions must be controlled to give equal pitting resistance in the austenite and ferrite fractions. Another indicator of pitting is the "Critical Pitting Temperature" which is found by exposing test pieces to 6%Fe (III) Chloride solutions and raising the temperature gradually until onset of pitting [29]-[30].

In developing pitting and crevice corrosion resistance in duplex grades alloy designers must try to obtain equivalent pitting resistance in both the austenite and ferrite (to prevent preferential attack of either phase) and must avoid the use of too high Cr and Mo levels to minimize the risk of precipitation of intermetallic phases.

III. Melt Quality

As well as Cr carbides and other precipitated phases, non-metallic inclusions or second phases containing impurities can have deleterious effects on the passive behaviour of stainless steels since these microstructural features not only give rise to discontinuities or defects in the thin passive oxide film but can also cause micro-galvanic corrosion cells. Sulphur will form sulphides which can generate hydrogen sulphide in acidic solutions or form galvanic cells which reduce corrosion resistance in the local areas around each inclusion. In producing ingot material, liquid metal improvements via vacuum and electroslag melting and refining processes have been made to produce the very low carbon and sulphur levels. These processes ensure the reduced levels of other impurities and inclusions that are especially required for the super stainless grades.

In arc melting of stainless-steel scrap for casting production final refining is normally achieved by AOD (Argon Oxygen Decarburization). AOD uses commercial high purity argon and nitrogen as well as oxygen injected through side tuyeres in a small converter type vessel. This allows carbon removal in the presence of high Cr concentrations and controlled introduction of nitrogen into the steel. Most steel foundries in Thailand use induction melting furnaces. For induction melting of stainless grades purer charge materials are required such as controlled quality wrought stainless scrap or special billet or ingot. Foundries that are familiar with producing higher C heat resistant steel castings such as parts for cement clinker and other grate plates cannot base production of corrosion resistant grades on similar types of charge materials. Heat resistant austenitic steel casting are not covered in the present paper and have been outlined elsewhere [31], [32].

In producing stainless steel melts based on scrap charges the nature of the scrap is critical. It must be clean and dry and be completely free from oils and other C bearing contaminants. Shapes such as bar stock, sheet and strip are acceptable if of known composition i.e. supplied with analysis certificate. Tube and pipe shapes must be not be used because of possible contamination from their internal surfaces. Any scrap that has been in service in carburizing conditions must be avoided. It must also be noted that the high Mn 200 series steels have become increasingly used in Asia, especially in India and China. Scrap from such Cr-Mn grades is not easily distinguished from the normal Cr-Ni material. Suppliers of stainless scrap and foundries in Thailand must take extra care to ensure that the 200 series material is effectively separated.

For cleaner lower C stainless grades Vacuum Induction Melting (VIM) and/or Vacuum Oxygen Decarburization (VOD) need to be used. These processes can be used for small tonnages of 1-20 tonnes in foundry applications. For duplex and superaustenitic grades AOD or VOD refining is needed to ensure that precise chemical compositions with the required low C, S, and other impurity levels are achieved.

During melt preparation liquid metal holding times and melt & pouring temperature temperatures must be as low as possible to decrease oxygen pick-up and promote cleanliness. The use of an Argon shield during melting, and if possible, during pouring, is recommended.

Feeding and running systems must be designed to prevent shrinkage defects in castings [33] and to minimize turbulence during filling of the mould cavities [34]. The materials used and production of moulds and cores and application of coatings must be selected not only to provide sufficient refractoriness to meet high pouring temperatures but also prevent the pick-up at cast surfaces of C, S and N from metal-mould interaction. Inorganic binders are preferable since organic binders tend to decompose when moulds are poured.

IV. Control of Microstructure and Heat Treatment in Castings.

The solubility of C in austenite decreases with temperature. Hence, alloy Cr rich carbides can precipitate if austenitic or duplex steels are slowly cooled, such as during cooling of a casting in a mould, or are held in service or otherwise in the temperature range of 350-850^{o}C. Precipitation usually occurs at grain boundaries in the austenite as illustrated earlier in Fig. 2 and in interdendritic zones. Segregation of C and Cr, and other carbide forming elements into the last regions of interdendritic liquid during solidification can give rise to interdendritic eutectic carbides. These are just as if not more damaging in promoting micro-galvanic attack as the carbides precipitated in the solid state. Therefore, castings must be annealed (solution treated) in the range of 1050-1175^{o}C (depending on composition) in order to dissolve any primary non-equilibrium eutectic carbides and any alloy carbide precipitates and then they must be cooled rapidly by water quenching to prevent any re-precipitation of carbides or other second phases.

Fig. 3 to Fig. 5 are used to illustrate that, without correct heat treatment, components used in the as-cast condition, will be prone to corrosive attack. Fig. 3 shows interdendritic eutectic carbide that has formed in the cast structure of a 0.2% C-20% Cr-18% Ni-6% Mo-0.18% N steel. This carbide together with dendritic segregation and possibly finer precipitated carbides has resulted in the corrosion damage seen in Fig. 4 and Fig. 5. The damage, produced during potentiostatic testing in chloride containing sulphuric acid, also illustrates the importance of controlling the % C to the lowest possible level. In this case, even after heat treatment, the large amount of alloying additions, which should give high pitting resistance, is wasted since the % C level is way over specification and should be below 0.03%.

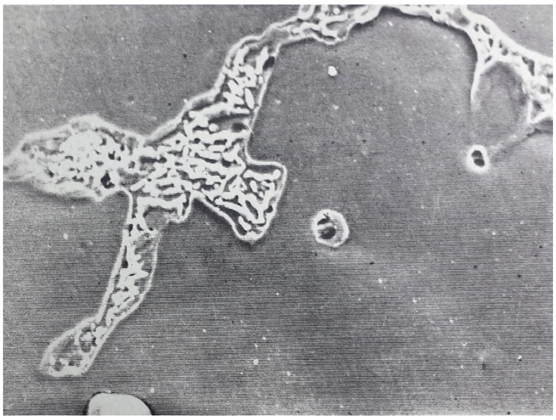

Fig. 3. As-cast microstructure of austenitic stainless steel containing excessive % C content showing the presence of interdendritic eutectic carbides (SEM x2000) [35].

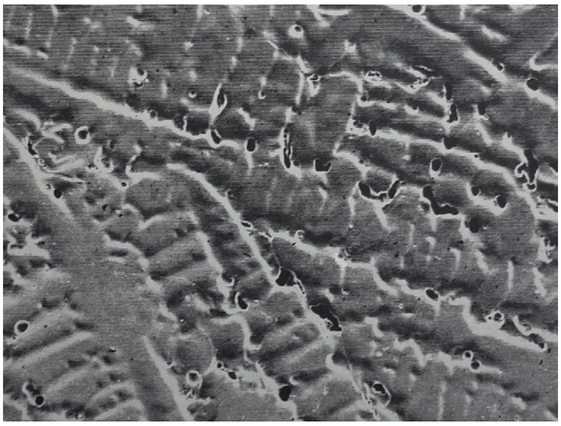

Fig. 4. Dendritic structure revealed by potentiostatic testing of the steel shown in Fig. 4 Pitting occurs at grain boundary and interdendritic regions (SEM x200) [35].

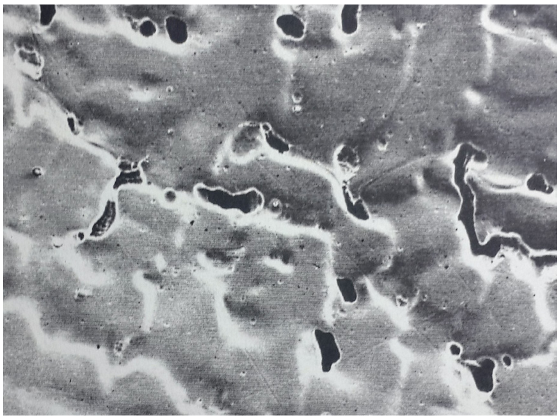

Fig. 5. The extent of interdendritic pitting seen in Fig. 4 (SEM x500) [35].

Duplex Grade castings must also be heat treated to remove segregation and to dissolve as cast carbides and precipitated second phases. The aim is to produce a precipitate free 50% ferrite - 50% austenite structure. Duplex grades present more problems than the austenitic grades since they are prone to the formation of a variety of embrittling precipitates such as sigma, carbides, nitrides, chi phases, etc. during slow cooling of castings after solidification. Secondary phase formation can be related to TTT diagrams for duplex steels as indicated in Fig. 6.

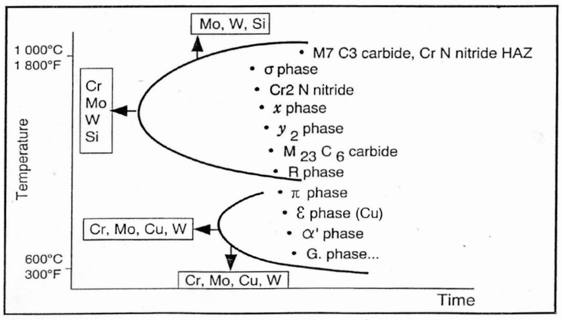

Fig. 6. A schematic Time-Temperature-Transformation diagram (TTT) for duplex stainless steel showing possible precipitating phases and the relative effects of alloying elements [16].

During production the castings must be left to cool to ambient in the mould to avoid cracking due to the presence of these precipitates. In the as cast state, there is a danger of cracking during feeder removal and fettling, especially for heavier sections. Hence before these cleaning operations castings often have to be solution treated to take the unwanted brittle phases into solution. Afterwards larger castings may require repeat heat treatment to remove any precipitation effects from the heat affected zones beneath removed feeders caused by thermal cutting or due to the inadequate cooling rate of the first treatment due to the mass effect of the previously attached feeder head.

For solution treatment castings must be charged into a cool furnace (below 250°C) and heated carefully at a maximum rate of 150°C per hour up to 700°C. They then should be held at 700°C for 1 hour per 25 mm of section to equalize temperatures in different sections and to ensure relief of stress before being raised, as quickly as possible, to 1175°C and held for 1 hr. per 25 mm of section. The heating rate from 700°C up to 1175°C needs to be rapid to minimize any second precipitation. The precipitation nose on TTT curves is around 850°C such that slow heating would allow formation of secondary phase precipitates, which in turn would result in excessive holding times for solution treatment in order to dissolve them.

Austenitic and duplex castings must be quenched from solution treatment temperatures into an agitated water bath where water can be rapidly recirculated by pumping from a second header tank. The transfer time before the quench must be minimal to prevent precipitation. With heavy section castings precipitation cannot always be prevented at the centres of sections such that although surface regions may meet specifications the centre sections may not. Therefore, producing bolt holes with cores rather than by drilling helps to lighten sections as does proof machining before final heat treatment in order to get the maximum depth of effectively heat-treated material.

Duplex grade castings may be tempered at 350°C after quenching to relieve residual stresses. It is not unusual for certain casting defects in larger steel castings to be subjected to weld repair. In these cases, castings must be given a post-weld solution treatment to ensure freedom from the danger of intergranular corrosion. Minor repair may be carried out without post weld treatment but only in very low carbon grades, (< 0.03%C).

The as-cast microstructure of duplex steel with a composition of 0.05%C-23%Cr-6%Ni-3%Mo-0.2%N is shown in Fig. 7. The secondary phases that have formed within the ferrite and at austenite/ferrite interfaces result in the pitting attack and removal of ferrite seen in Fig. 8 to Fig. 11 illustrate the effects of correct and incorrect heat treatment of the as-cast steel shown in Fig. 7 and Fig. 8.

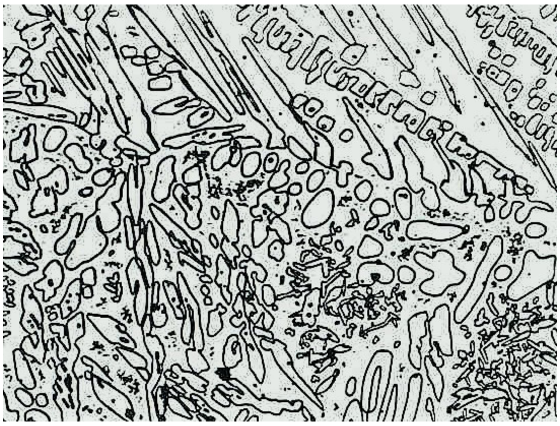

Fig. 7. As cast microstructure of duplex stainless steel showing blocks of austenite in a ferrite matrix which also contains precipitated secondary phases (Optical view x75).

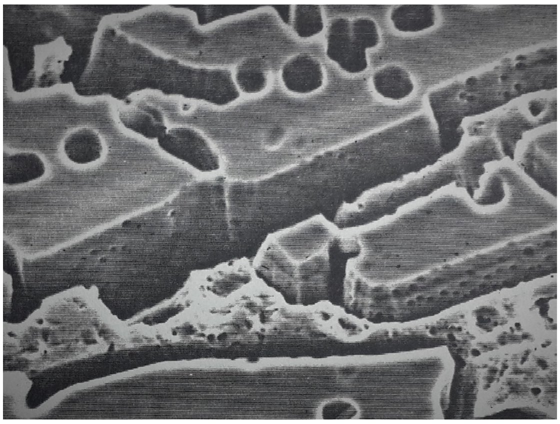

Fig. 8. Corrosion damage produced during potentiostatic testing in 3.5% sodium chloride solution. Ferrite is preferentially removed with pitting damage in the ferrite and at the austenite/ferrite boundaries (SEM x3000) [35].

Quenching should prevent precipitation of carbides and any other secondary phases during cooling. Solution treatment at 1175°C followed by effective water quenching has prevented the formation of secondary phases in the ferrite such that relatively littles corrosion has occurred during potentiostatic testing in 3-5% sodium chloride solution as shown in Fig. 9.

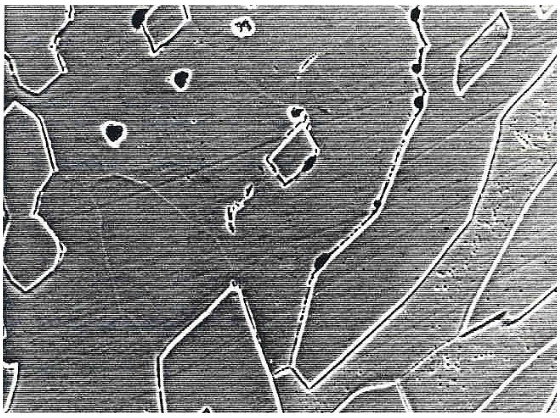

Fig. 9. Correct solution treatment: pitting at isolated non-metallic inclusions with some smaller pits in some ferrite areas (SEM x1000) [35].

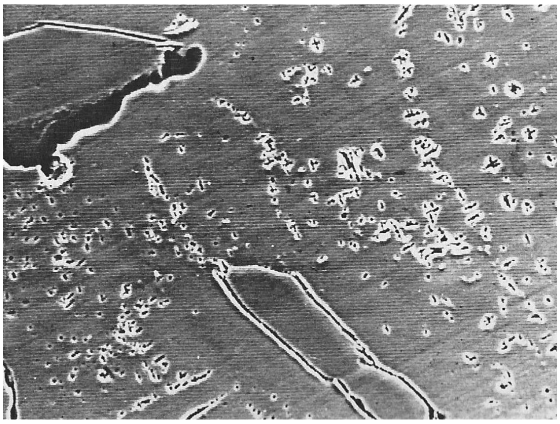

Fig. 10. The effect of a time delay before water quenching after solution treatment. Some precipitation has occurred in the ferrite and at ferrite/austenite interfaces giving pitting damage (SEM x1000).

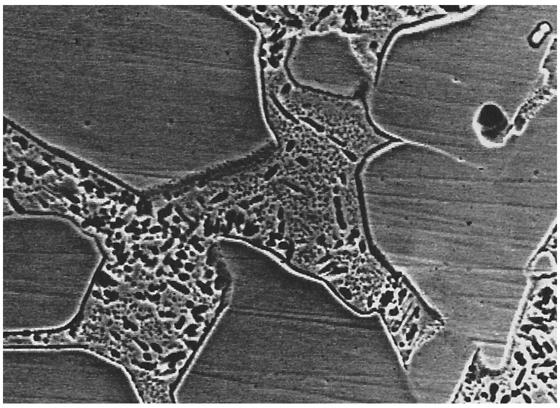

Fig. 11. Incorrect solution treatment. Slow cooling has resulted in extensive secondary phase formation that has caused severe pitting in the ferrite areas. There is no pitting in the austenite except at interphase boundaries. The microstructure and corrosion damage are similar to the as-cast condition in Fig. 8 (SEM x1000).

However, any delay before quenching will allow some precipitation to occur and hence result in pitting damage in ferrite as shown in Fig. 10. Slow cooling from 1175°C is highly damaging since this allows considerable secondary phase formation and results in severe damage in the ferrite as shown in Fig. 11. To obtain comparative corrosion behaviour the damage seen in Figs. 8 to Fig. 11 was produced by holding each specimen in the trans-passive region to give 50mA/cm^2 current density for 1 minute. The small number of relatively large pits seen in Fig. 9 have resulted from the presence of non-metallic inclusions. The avoidance of such pits highlights the importance of producing "clean" steel.

The passivation behaviour of 4 cast stainless steels in the solution heat treated condition is shown in Fig. 12 in the form of potentiostatic scans obtained during testing in de-aerated stirred 0.1M H_2SO_4 using a saturated calomel electrode (SCE) as reference. The steels, whose compositions are also shown, were produced and heat treated in industry. Steels A, D and C are duplex grades while steel B is austenitic containing some 15-20% ferrite. The duplex steels were water quenched from 1175°C and then stress relieved at 350°C. Steel B was water quenched from 1150°C and does not normally require subsequent stress relief. Corrosion data from these curves is given in Table II as values for E_{pp}, i_{crit} and i_{pass} together with the ACI alloy type designation of each steel.

E_{pp} indicates the peak passivation potential at which the maximum rate of anodic dissolution occurs at a critical value of the current density i_{crit}. The smaller the value of i_{crit} the greater is the tendency for the alloy to passivate. Once passivation has occurred the minimum rate of corrosion in this state is indicated by i_{pass} [36], [37]. As the potential becomes more positive there is a rapid rise in the current density and pitting can occur: this is called the transpassive region. For ease of passivation of a steel (i.e. reduced corrosion rate) a combination of a more negative E_{pp} and low values of i_{crit} and i_{pass} and a wide passive range is required.

Also given in Table II are the equivalent data from steel A (CE8Mn) in the as-cast condition. The data shows that solution heat treatment of this steel has reduced the current density i_{crit} for passivation from 125 to 100 μA/cm^2 and i_{pass} from 60 to 30 μA/cm^2.

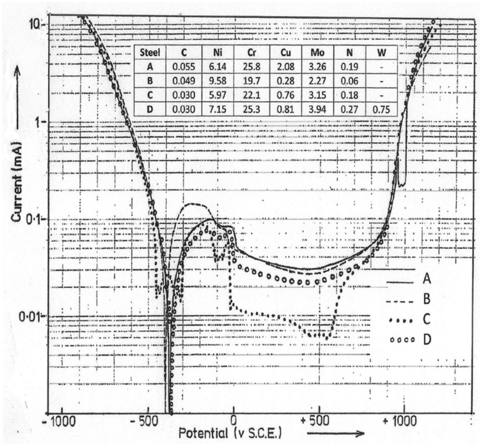

Fig. 12. Potentiostatic scans in 0.1M sulphuric acid

TABLE II
DATA FROM FIGURE 12 WITH EQUIVALENT VALUES FOR STEEL A IN THE AS-CAST CONDITION

Steel	Alloy Type	E_{pp} (mV v SCE)	i_{crit} (μA/cm^2)	i_{pass} (μA/cm^2)
A	CE8MN	-150	100	30
B	CF8M	-250	140	27
C	CD3MN	-200	90	6
D	CD3MWCuN	-150	78	23
A (As-cast)	CE8MN	-160	125	60

As explained earlier solution heat treatment takes any damaging intermetallic phases such as sigma that are formed in the as-cast structure into solution at high temperature with subsequent rapid cooling by water quenching preventing their reformation. It also allows homogenization of the distribution of alloy elements in solid solution in the austenite and ferrite phases. Stress relief treatment at 350°C does not normally result in any subsequent precipitation of carbides or other phases.

The austenite grade (steel B) shows similar passivation behaviour to the duplex grades but, for service applications, it is disadvantaged by low yield strength (0.2% proof stress) of 337 MPa when compared to the duplex grades. Steels A, D and C have yield strengths of 667, 544 and 617 MPa respectively.

The PREN values calculated from composition for the four steels are as follows: for A-40, B-28, C-35 and D-43. For the duplex grades these values suggest that steel D should show better passivation than steels A and C. However, steel C with the lowest alloy content of the duplex grades had the smallest value of i_{pass}. For the solution treated condition, steel

A showed a higher i_{pass} value than the C and D. This was due to its higher %C content of 0.055wt.% and the presence of patches of carbide precipitation in some ferrite regions in the microstructure. Consequently, during testing this steel suffered from pitting damage. The dual-peak nature for passivation potentials seen in the scans is most likely due to the presence of both austenite and ferrite in the microstructures but needs further study together with why the leaner duplex grade steel C showed unusually better passivation than the super-duplex grade steel D.

The tendency for secondary phase formation in duplex grades, as indicated by Fig. 6, provides a complex problem and in practice means that these grades cannot be used at temperatures above 350°C. Secondary phase formation significantly reduces toughness. Work on wrought 22Cr-5Ni-3Mo duplex has shown that the V-notch Charpy toughness falls from 150-175J to 100J when 0.5% volume fraction of secondary phases are present. For 1% of second phases the impact toughness falls sharply to 50J and to below 25J when 2% or more is present [38]. Similar levels of reduction are expected in cast grades.

To characterize the various secondary phases that may form during solidification and heat treatment transmission electron microscopy coupled with advanced micro-analytical procedures are necessary. For example, the transformation sequence and types and compositions of complex carbide and secondary phases formed in a 22Cr-3Mo-6Ni duplex casting grade have been identified [39]-[41]. Figs. 13-Fig. 15 show how atomic number contrast in back scattered electron SEM images can reveal the phases present in a 0.37C-22Cr-6Ni-3Mo-0.2N-0.75Cu duplex steel in the as-cast, solution treated, and after holding post-solution treatment for 16h at 900°C. The phases seen in Fig. 13-Fig. 15 have been identified by TEM electron diffraction as ferrite (δ), primary austenite (Υ_1), secondary austenite (Υ_2), sigma phase (σ) and chi (χ) [40], [41].

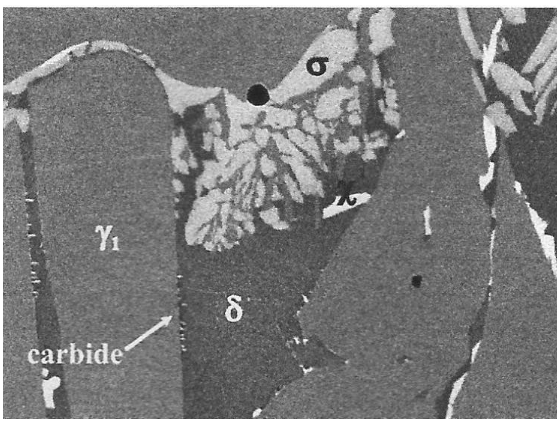

Fig. 13. As-cast microstructure of duplex SS showing various phases identified (SEM BSE x1000) [40].

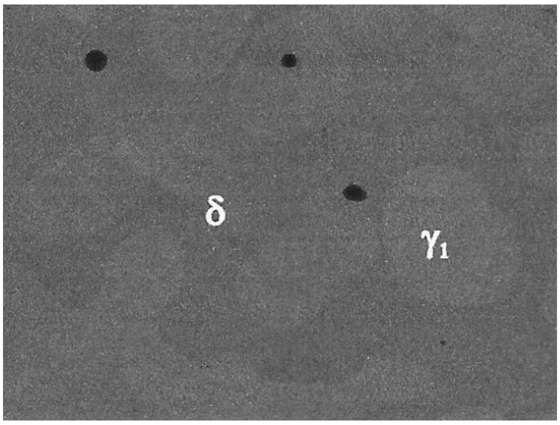

Fig. 14. Correctly solution treated condition (Water quenched from 1175°C. Only ferrite (δ) and austenite (ϒ) are present (BSE SEM view x1000) [40].

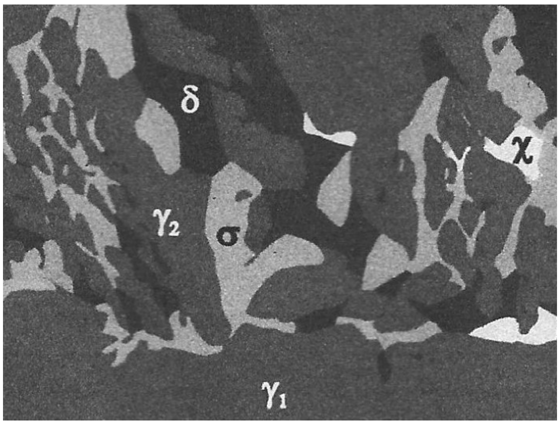

Fig. 15. Phase present after holding at 900°C for 16h (BSE SEM view x1000) [40].

V. Conclusion

In producing any stainless steel casting, the surface condition, cleanliness, soundness and freedom from other defects such as laps or tears are significant. Non-metallic inclusions may lead to localized pitting. Micro-porosity reduces pressure tightness and provides pathways for corrosion, and as for rough surface finish, may lead to increased rate of erosion-corrosion in pumps or impellors. Heat treatment, any weld repair and post-weld heat treatment must all be correctly carried out.

In S.E. Asia, some steel jobbing foundries often encounter difficulties when asked to produce corrosion resistant replacement parts for equipment which, having originally been manufactured overseas, now needs repair. In such cases low cost is often the major consideration, and if the relevant metallurgical and corrosion aspects are ignored, then the end result may be early or catastrophic failure in service with serious safety and financial consequences. Foundries must understand any customer requirements for castings that require particular corrosion resisting properties.

In Thailand the domestic demand for steel products (both long and flat) in 2018 was approximately about 17 million tones. For these, the domestic production was only 40% [42]. The demand for stainless steel, especially shaped casting products will increase with the demand for electric vehicles and the promotion of mega infrastructure investments such as the three airports rail links and other smart city transportation projects [43]. Thai stainless steel foundries need to apply good manufacturing practices in order to be able to compete with the imported products from China, Japan, Malaysia, Taiwan, and South Korea. Appropriate pre and post-treatment controls denoted in the paper should be able to provide guidelines on cast stainless steels for operation and quality assurance in the workplace.

Due to the complex nature of observed corrosion damage and electrochemical corrosion data which in turn are influenced by composition, casting section thickness and heat treatment, there is still considerable scope for further research on cast stainless steels. Microstructures in castings are coarser, contain both macro and micro-forms of segregation and can contain a greater variety of intermetallic phases when compared to wrought grades, hence, in addition to more intense corrosion studies, there is a need for improved melt treatments to refine primary grain sizes, detailed microstructural TEM characterization especially of the fine carbide/nitride precipitates and other intermetallics that may form, and optimization of weld repair and heat treatment conditions. For example, probe techniques such as Scanning Kelvin Probe Force Microscopy (SKPFM) which have been successfully used to obtain valuable data in wrought duplex steels need to be applied to study casting grades [44].

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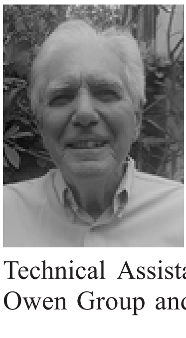

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Super Resolution Based Augmentation for Image Classification on Small Data Set

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Abstract—**For image classification to be more accurate, image files with high resolution were to be put up for test. Practically, the set of images obtained for classification might be low resolution files. In this case, it was more difficult to do image classification. The result was that the accuracy rate was low. It was unable to be applied for work. We studied to find a solution to fix this problem. The answer to the problem was to do data augmentation which was consisted of Affine Transformation and Super Resolution. Affine Transformation are all linear transformations which can be represented by a matrix and combined into a single overall including rotation, scaling, translation and shearing where all points in an object are transformed in the same way.**

Image Super Resolution made to increase the high resolution and quality for image. This method has been shown that it outperformed the basic interpolation method. In this research, we studied whether Super Resolution is able to enhance the analyze model of the image and then transformed image is more responsible to image classification process. It can be seen that the methods applied were useful to accurately and precisely identify low resolution image files. Besides, we adopted a transfer learning method which was designed and developed for the task. It has been reused the first starting point form model in the second task could help us classify the type of image more accurately and precisely.

Index Terms—**Image Classification, Data Augmentation, Transfer Learning, Image Super Resolution**

I. Introduction

Up to this day, Computer Vision is well recognized by common people since it works to process images so that the computer would understand the image or be able to distinguish objects as close as to what a human brain does. There are 4 types of Computer Vision including image classification, object detection, semantic segmentation and instance segmentation. Each type has its own function. The one matched to our experiment is Image Classification. For the past few years, doing image classification has become an interesting subject - its objective was to classify the type or character of image precisely with minimum error. The experiment was separated into 2 sections. One was to teach the computer to test the prepared testing data for classification before inputting the actual set of data for classification. It found that we could well classify the dataset with the big size or a lot number of images in the testing set and actual set. What we have found to be an obstacle to this experiment was that we could not know if how many actual images were obtained. In certain case, there might be the situation that the actual data obtained was consisted of small-sized image or less number of images. After conducting classification, the outcome was unable to be adopted to actual work because of many factors. Therefore, we suggested to use Data Augmentation and Image Super Resolution were applied for image classification in degree that to increase quality for images to its highest. This would also help us to do classification easier and increase the level of accuracy in image classification. The technique of image augmentation or affine transform was applied for minimizing the loss and diversity of data because the more testing data it obtained, the more accurate it would be. The basic techniques were consisted of Flip, Mirroring, Scale Image, Translation, Crop and Rotation. Meanwhile, using Image Super Resolution to enhance resolution and quality of image has been found to be more eligible and efficiently for classification according to the research. After the dataset was managed, Transfer Learning was additionally applied to do classification so that the dataset could be classified faster. Besides, Convolutional Neural Network was also used for classification.

II. Objective

- To categorize images from a small dataset into image types and image sizes.
- To propose a solution for small dataset classification.
- To develop a Data Augmentation Technique to be more efficiently and accurate.
- To use the limited dataset for image classification even if normally it requires a big dataset to do so.
- To increase the quantity for images and enhance quality for small images files so that it can be used flawlessly.

III. Literature Review

Before we conducted this research, we had been researching similar work with the corresponding objective including problems. The subject we studied more was related literature with the details as follows: For image classification, mort of the research concerned about detection and object categorization segmentation. These techniques were basic techniques adopted to the research. For data augmentation, we included many forms such as image super resolution, using of GAN and Affine Transform in both basic form and applied form for 3D transformation which transform image from Transform Version to Original Version. The technique of Affine Transform jointly applied with other Classification technique.

IV. Related Work

To do image classification, the model's resolution must be high enough so that it can be classified easier. It also prevents overfitting. When model trained with small images training dataset, the trained model tends to overly fit to the samples in training set. Moreover, there was another problem that images in a small training set were usually incomplete and low quality it could not be classified. It also worsened the results in generalization. However, The Data Augmentation have been widely to used avoid this overfitting problem by enlarging the size of images training dataset which increased the number of date by Crop, Translation, Scale Image, Mirroring, Flop and Rotation. Even though the image could be adjusted and improved, the existing hyper parameter did not help improve the image resolution as the date was small and it was possibly that the image with low quality would be mixed up in the same set. Therefore, we adopted the technique of Image super resolution to help fixing this problem. Image super-resolution methods attempted to recover a high-resolution image from one or more low-resolution input images. This disadvantage for image super resolution in some cases was that the image would be distorted from the original. Eventually, there would be a mistake in classification process.

V. Techniques

A. *Image Super Resolution*

Image super-resolution methods attempt to recover a high-resolution image from one or more low-resolution input images. Super-resolution methods can be classified in two main families: Multi-image Super Resolution methods, and Single Image Super Resolution methods (SISR). Multi-image Super Resolution methods attempt to use several low-resolution images of the same scene to determine new details in the high-resolution image, In addition, these methods tend to be limited to small increases in resolution [1], [2].

B. *Data Augmentation*

Data augmentation is a strategy that enables practitioners to significantly increase the diversity of data available for training models, without actually collecting new data. Data augmentation techniques such as cropping, padding, and horizontal flipping are commonly used to train large neural networks [3].

C. *Transfer Learning*

Transfer learning is a machine learning method where a model develop for a task is reused as the starting point for a model on a second task [4].

D. *Computer vision*

Computer vision is the field of computer science that focuses on replicating parts of the complexity of the human vision system and enabling computers to identify and process objects in images and videos in the same way that humans do. Until recently, computer vision only worked in limited capacity [5].

E. *Convolutional Neural Network*

The structure of artificial nerve has consisted of an input layer, a hidden layer, and an output layer, or commonly called multi-layer perceptron (MLP). However, the research presented by Le Cun et al. and has added convolutional calculation into such neural network – it is called Convolutional Neural Network (CNN). CNN is consisted of a pooling layer and a fully-connected layer which is a hidden layer and an output layer appeared in the artificial neural nets. CNN is able to extract special characteristics of photo and second-class category. The outstanding point of CNN is different from machine learning which categorize only type of information or organize them into groups [6], [7], [8].

- VGGNet.

VGGNet is a deep CNN structure since there are 16 layers by using Kernel of 3x3 in convolution. VGGNet-16 is consisted of 5 groups of convolution. The first Conv or Conv1 is consisted of Conv1{1,2} and there are 64 Kernel in each layer. Conv2 is consisted of Conv2{1,2} which has 128 Kernels. Conv3 is consisted of Conv3{1,2,3} which has 256 Kernels. Conv4 is consisted of Conv4{1,2,3} which has 512 Kernels. Conv5 is consisted of Conv5{1,2,3} which has 512 Kernels. Conv1-5 is followed by max pooling. Then the information is linked to fully-connected layer with 4,096 nodes. In the final layer, it is designed to have 1,000 nodes. The outcome is calculated by a software [9].

VI. Methodology

The goal of the project was to determine whether Image Super-resolution and Data Augmentation can be used as a pre-processing step to improve classification accuracy. Experiments were carried out by using general image classification datasets.

A. *Image Super – Resolution*

Image super-resolution methods attempt to recover a high-resolution image from one or more low-resolution input images. Super Resolution methods attempt to use several low-resolution images of the same scene to determine new details in the high-resolution image, In addition, these methods tend to be limited to small increases in resolution [1], [2].

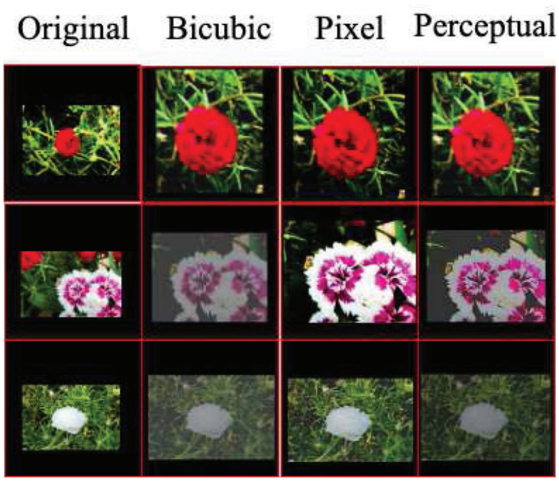

Fig. 1. Images are shown before versions transformed with up sampling method.

B. *Convolutional neural networks for Image Super-Resolution*

First way to know if SISR is using deep learning can be traced back to [10], where three layers of CNN named SRCNN is made to solve the problem in a very effective way. This simple but light structure have three portion as: (1) Patch extraction layer (2) Non-linear mapping (3) Reconstruction they directly consider a convolutional neural network which is an end-to-end mapping function between photos with different resolution. The reason why this is a surprising invention is that they are made to match the easy in mind, and yet give great accurate and quickness even compared the model example-based method.

1) Patch extrtaction and representation

This operation extracts (overlapping) patches from the low-resolution image Y and represents each patch as a high-dimensional vector. These vectors comprise a set of feature maps, of which the number equals to the dimensionality of the vectors.

This a operation extract patches form low-resolution images and shown each patch a high-dimension:

$$F_1(Y) = \max(0, W_1 * Y + B_1)$$

W1 and B1 represent the filters and biases respectively, and '*' denotes the convolution operation.

2) Non-linear mapping

This operation non-linearly maps each high-dimensional vector onto another high-dimensional vector. Each mapped vector is conceptually the representation of a high-resolution patch. These vectors comprise another set of feature maps.

This operational nonlinearly maps each high-dimensional vector onto another high-dimensional vector. Each mapped vector is conceptually the representation of a high-resolution patch:

$$F_2(Y) = \max(0, W_2 * F_1(Y) + B_2)$$

W2 contains n2 filters of size n1 ×f2 ×f2, and B2 is n2-dimensional. Each of the output n2-dimension vectors is conceptually a shown of a high-resolution patch that will be used for reconstruction.

3) Reconstruction

This operation sums up the above high-resolution patch-wise shown create the last high-resolution image. The image is expected to have a similar to ground X axis.

In the last methods, the predicted overlapping high-resolution patches are often averaged to produce the final high-resolution image :

$$F(Y) = W_3 * F_2(Y) + B_3$$

W3 corresponds to c filters of a size n2 × f3 × f3, and B3 is a c-dimensional vector. If the representations of the high-resolution.

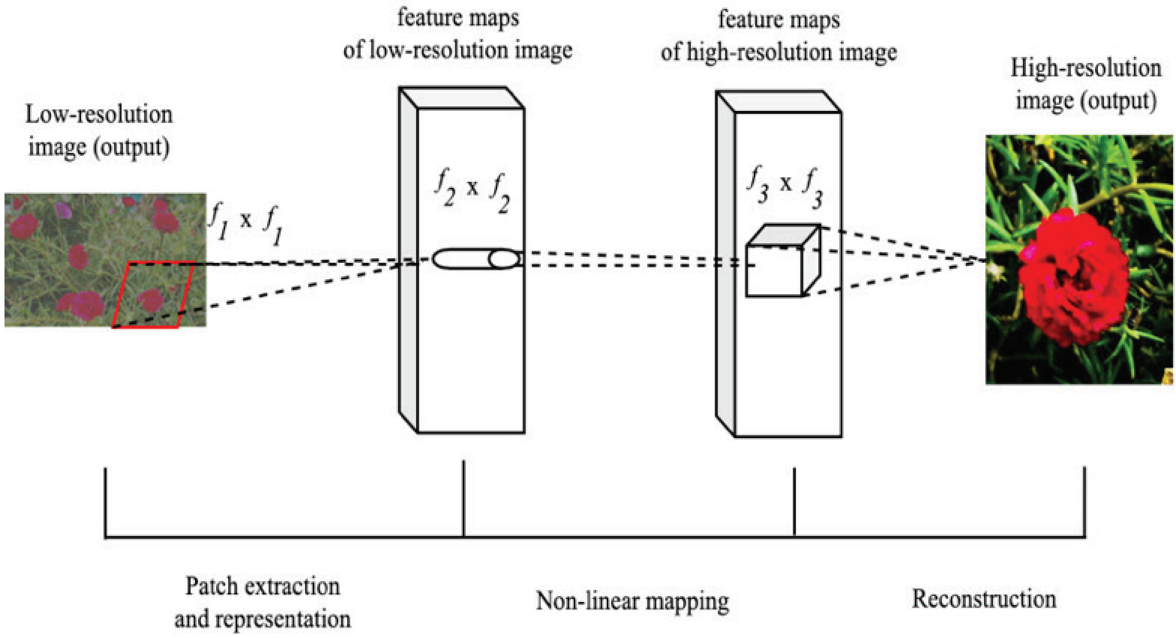

Fig. 2. CNN for Image super-resolution classification

C. Affine Image transformation

In the first method, we are going to define and apply a set of geometrical transformations called affine transform. We will present basic affine transform translation, rotation, scale, shearing.

1) Translation

A Translation is a function move every points in a fixed distance in Fig. 3 (a)

$$T = [T_x, T_y]$$

T_x Distance from the horizontal axis

T_y Distance from the horizontal axis

2) Scaling

A Scaling is a linear transformation that set of points up or down in the same all directions. Zoom in on the x and y axis in Fig. 3 (b)

$$x' = x \cdot S_x$$
$$y' = y \cdot S_y$$

S_x = Scale factors form x axis

S_y = Scale factors form y axis

3) Rotation

A Rotation is a circular transformation that a set of points about the origin. in Fig. 3 (c)

$$x' = x \cos \emptyset - y \sin \emptyset$$
$$y' = y \sin \emptyset - x \cos \emptyset$$

4) Shearing

A Shearing is a function offsets a set of points a distance proportional to x and y. The twisting of the x axis 2. The twisting of the axis of the image causing the point to move (x) to (y) after that the twisting of the x axis causes the point to be moved (x, y) to (x′, y′) in Fig. 3 (d)

$$x' = x$$
$$y' = Shy.x + y$$
$$x' = Shx.y + x$$
$$y' = y$$

Shx = Shearing factor form x axis

Shy = Shearing factor form y axis

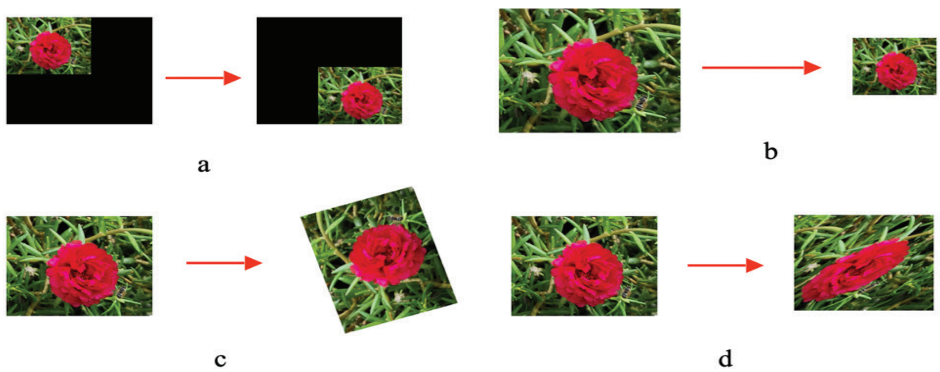

Fig. 3. Affine transform: Translation, Scaling, Rotation, and Shearing

D. Datasets

1) Kaggle flowers

The dataset have 4242 images flowers. This dataset have portioned five classes (1) chamomile, (2) tulip, (3) rose, (4) sunflower, and (5) dandelion. For each class there have 800 images colour in per 1 class. Images not high resolution and this size 320x240 pixels. Photos are not reduced to single size, that have other proportion. in order to test the effects and affine transform of super-resolution on classification performance [11].

2) Oxford_flowers 102

Dataset is a consistent of 102 flower categories commonly occurring in the United Kingdom. Each class consists of between 40 and 258 images. The images have large scale, colour, pose and light variations. In addition, there are categories that have large variations within the category and several very similar categories in order to train and test the effects of super-resolution and affine transform on classification performance [12].

3) Oxford_flowers 17

Datasets is a consistent of 17 category flower dataset with 80 images for each class. The flowers chosen are some common flowers in the UK. The images have large scale, colour, pose and light variations and there are also classes with large variations of images in order to train the effects of super-resolution and affine transform on classification performance [13].

E. Experiments

We use a standard per-pixel loss function to train a set of up scaling filters. We will refer to this as the pixel loss method. The second approach was a standard bicubic interpolation, mainly to be used as a control. We trained network for 100 epochs, and a learning rate of 1e-3 using an Adam optimizer.

We hypothesize that using a transform factor which scales in addition, scaling, translation, rotation and shearing were applied to the training data for all trials. The network was trained to upscale consist of. We trained and tested a standard VGG-net classifier which is composed of a standard VGG net with a few layers added simply to account for the larger image sizes (128x128 of 96x96 as opposed to 32x32). A 16-layer VGG network was used for classifying the original 32x32 data, and a network with 4 additional layers was built from that to fit the 96x96 up sampled data.

In Fig. 12, it explains about the data in a training set which is divided into 2 sets including: Kaggle Flowers which contains 4,242 photos and Oxford_flowers102 which contains 102 categories.

The dataset includes in a training set can be portioned a validation set and a testing set. Each per them include 10 images for one class, totaling 6, 149 images per one set.

In Fig. 13, it explains about the data in the test set which applied 1 set (Oxford_flower17). It contains 17 categories. In each class, it contains 80 images.

Oxford_flowers102 which contains 102 categories. This testing set include for remaining 1,020 images (minimum 20 in one class).

In experiment, I am going to use examples of VGG 16 pretrained model throughout this guide. We can use other pretrained models similarly.

The main pattern was consisted of CNN which we used VGG NET and Transfer Learning. In the subsection, we divided into 3 patterns including: (1) Classification via Transfer Learning and Convolutional neural network without using Data Augmentation and Image Super-Resolution, (2) doing Classification via Transfer Learning Convolutional neural network using Data Augmentation but not using Image Super-resolution, (3) doing Classification via Transfer Learning Convolution neural network using Image Super-resolution but not using Data Augmentation, and (4) doing Image Classification via CNN, Transfer Learning and using Data Augmentation and Image Super-resolution. From the experiment.

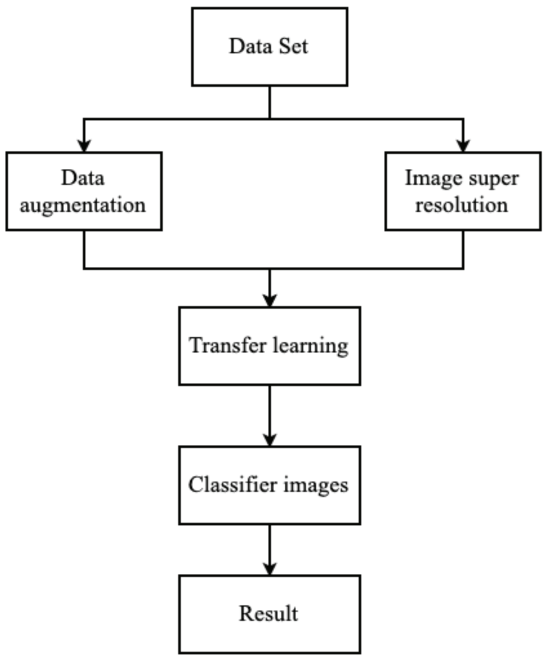

Fig. 7. Overall Methods of Image Classification

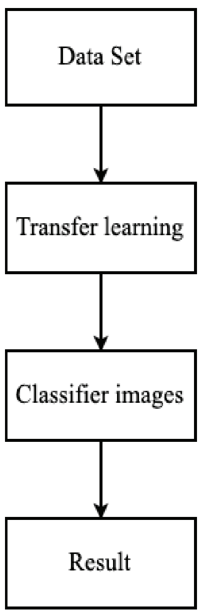

Fig. 8. Methods - 1 of Image Classification

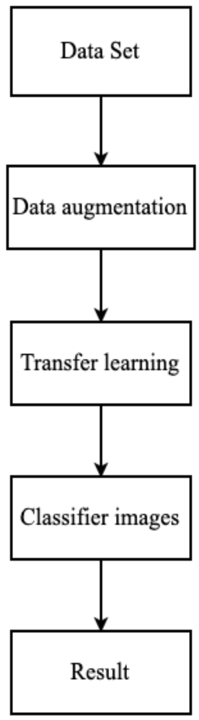

Fig. 9. Methods - 2 of Image Classification

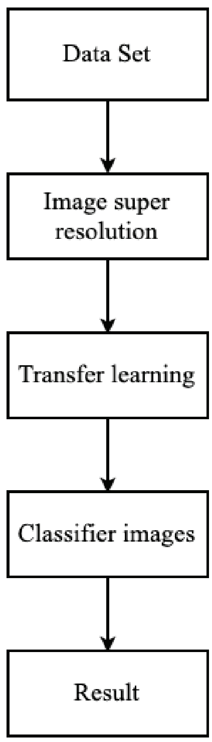

Fig. 10. Methods - 3 of Image Classificat

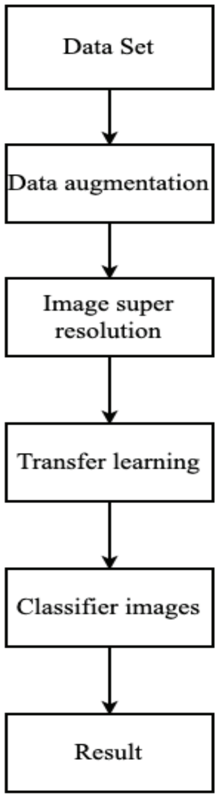

Fig. 11. Methods - 4 of Image Classification

VII. RESULT

A variety of image super-resolution, Data augmentation techniques, CNN, transfer learning and image classification. Experiment have proceeded involving general and small Image datasets.

Fig. 12, we compare our results train dataset form train with methods 1- 4 on VGGNeTs for fine-grained classification in basic dataset. Fig. 13, we compare our results test dataset form train with method 1- 4 on VGGNeTs for fine-grained classification in small data set. Evaluation on effect of methods 1- 4 which will see the process on methods 4 have a high accuracy more than methods 1-3 that method have to recovery high resolution details for images. In our experiments, we used Macbook Pro with Google Colab .

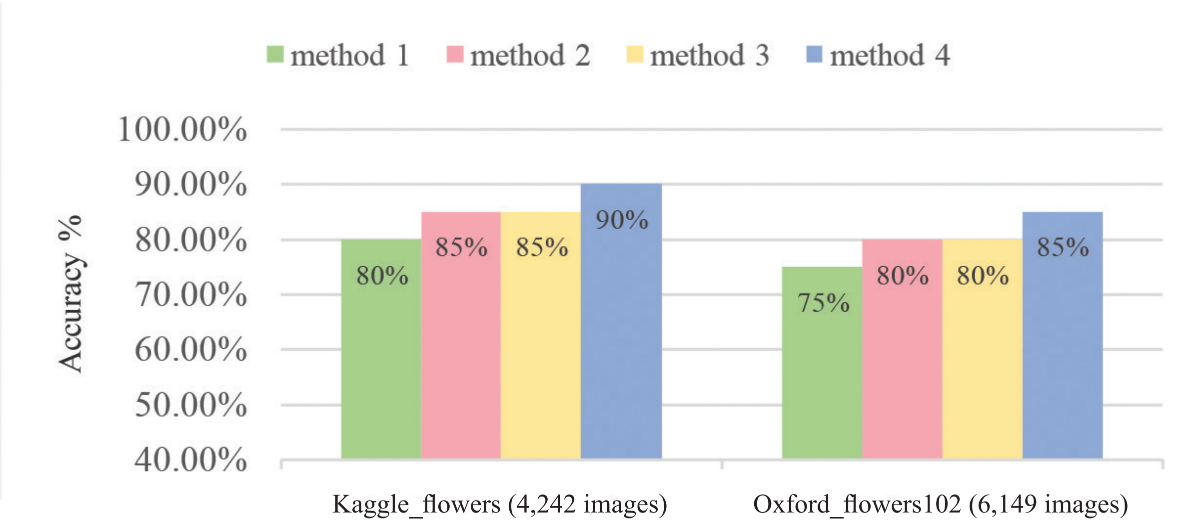

Fig. 12. Accuracy result of train methods compare result basic dataset for train with 1- 4 methods on vggnets

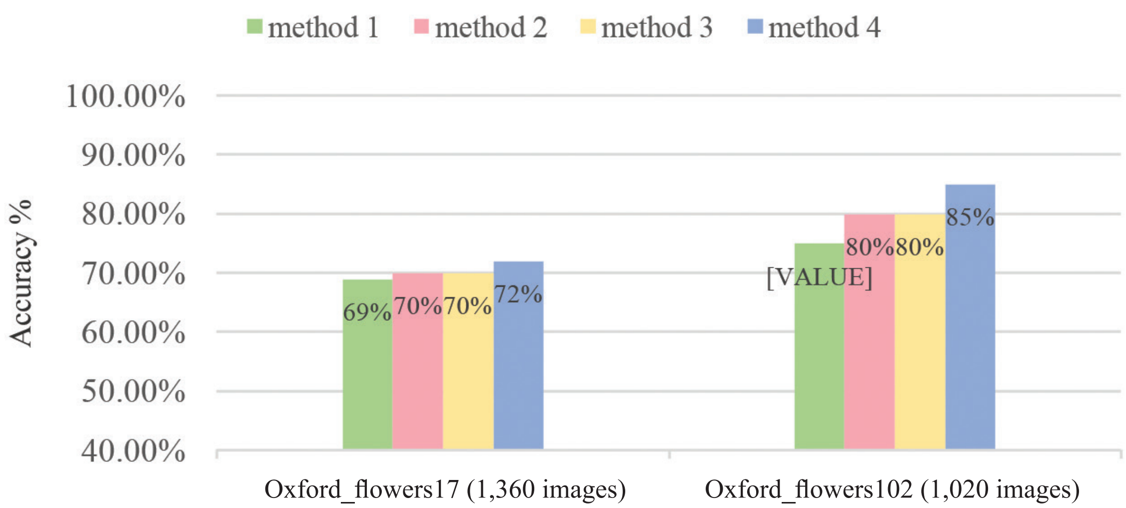

Fig. 13. Accuracy result of test methods compare result basic dataset for test with 1-4 methods on vggnets
Note: The effect of the presented methods depends on dataset

VIII. Conclusion

We proposed that applying the new and former techniques to create an image enhancing process with the Image Classification gave us a better outcome that was corresponding with our need. However, it was not the best outcome we expected since we had incomplete images. The problem we have found from adopting several techniques together was that in each technique had its own complication. Therefore, the outcome was inaccurate. For example, the image was twisted from the original. In an overall, adopting several techniques together provided a better outcome but it could not fix all problems. In the future, these techniques should be further developed and used as a basic technique for classification with the limited data. Even though it has been through data augmentation process, some images were unusable–the dataset was unable to be adopted for work. In the future, we may develop these techniques to be more efficiently in case that we have limited dataset which is required to be used.

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[7] E. P. Wigner, "Theory of traveling-wave optical laser," *Phys. Rev*., vol. 134, pp. A635–A646, Dec. 1965.

[8] E. H. Miller, "A note on reflector arrays," *IEEE Trans. Antennas Propagat*., to be published.

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[11] J. H. Davis and J. R. Cogdell, "Calibration program for the 16-foot antenna," Elect. Eng. Res. Lab., Univ. Texas, Austin, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.

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[39] B. Smith, "An approach to graphs of linear forms," unpublished.
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