

ISJET

INTERNATIONAL SCIENTIFIC JOURNAL OF ENGINEERING AND TECHNOLOGY

Volume 3 No. 1 January-June 2019

ISSN 2586-8527 (Online)

Panyapiwat Institute of Management

Indexed in the Thai-Journal Citation Index (TCI2)

INTERNATIONAL SCIENTIFIC JOURNAL OF ENGINEERING AND TECHNOLOGY (ISJET)

Volume 3 No. 1 January-June 2019

ISSN 2586-8527

PANYAPIWAT INSTITUTE OF MANAGEMENT

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Volume 3 No. 1 January-June 2019
ISSN 2586-8527

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Published by
Chulalongkorn University Printing House
Bangkok, Thailand
Tel. +66(0) 2218 3549-50
Fax. +66(0) 2215 3612
http://www.cuprint.chula.ac.th
E-mail: cuprint@hotmail.com

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INTERNATIONAL SCIENTIFIC JOURNAL OF ENGINEERING AND TECHNOLOGY (ISJET)

Volume 3 No. 1 January-June 2019 ISSN 2586-8527

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Frequency of Publication:
Twice a year
• The first issue: January - June
• The second issue: July – December

Publication and Access Charges:
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Volume 3 No. 1 January-June 2019
ISSN 2586-8527 (Online)

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INTERNATIONAL SCIENTIFIC JOURNAL OF ENGINEERING AND TECHNOLOGY (ISJET)
Volum 3 No. 1 January-June 2019
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Dear Colleagues,

On The path of Thailand 4.0, many organizations have deployed and carried on the project to improve their business in many ways. For example one of the mega project is to develop fuel depot in Pichit and Lampang province in the northern part of Thailand and pipeline system to transfer the oil with the project value of 3,000 million Baht that will change the oil logistic system in Thailand. Such project can be the benefit in many ways such as reducing air pollution that created from truck transportation, reduce accident on road, sustain oil in northern part of Thailand which can be used for transportation, agriculture and many more. Technology and engineer are one of the very important aspects that can make the impossible possible.

International Scientific Journal of Engineering and Technology (ISJET) keeps moving on along with the new and changing technology to present the new research information that can benefit the various organizations. We would like to thank all contributors for their valuable research in engineering and technology including using social media, technology, transportation, and manufacturing. Such information will be a great knowledge in many organizations and crucial for their business. We would like to urge you to continue support our journal with your valuable research.

Finally, on behalf of the Editorial Board, we would appreciate feedback from you, the readers of and contributors to the ISJET. Hence, you are encouraged to contact the Editors or the journal coordinator on any aspect of the journal. Your input is, as always, highly valued as it helps up improve further the quality of our offering.

With Kind regards,

Asst. Prof. Dr. Phannachet Na Lamphun
Associate Editor of Engineering

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Assessment of Mental Workload by Subjective Analysis Technique and Electroencephalography in the Sample Program Testing

Prachuab Klomjit, Phitsini Thanawiwat and Sasi Ninlawat

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Received: August 16, 2018/ Revised: September 10, 2018/ Accepted: October 26, 2018

***Abstract* —The purpose of this research was to study the assessment of mental workload by subjective analysis technique and electroencephalography in the sample program testing. The different types of the workload were assessment as follow: Evaluation of Posture Operation by RULA, Windows and Android operating systems and Manual.**

A performance of the research was divided on these three parts. First, studied and reviewed of the evaluation. Second, applied the evaluation form, NASA TASK LOAD INDEX (NASA-TLX) and compared with the brainwave of electroencephalography (EEG). Third, estimated and compared the performance of workload.

A result of the assessment of mental workload by subjective analysis technique and electroencephalography. It can be concluded that. Evaluation of Posture Operation by RULA method. The heaviest workload is evaluated work postures using manual calculations. The minimum workload is RulaSU Android operating system.

***Index Terms*—Ergonomics, Cognitive, Mental Workload, Electroencephalography (EEG), RULA.**

I. Introduction

Working with certain tools affects both the body, thinking and mind, such as manual handling, machine control, and inspection. The mental workloads are including heavy duty vehicle inspections, large truck drivers, large-scale surveillance and control systems in the control room. An also, including product design, computer program design applications. The result is not only a physical burden, but It also affects the thinking and mind. This could reduce the quality, performance decrease and misused or work more. And also, it can lead to many accidents and losses.

The assessment of workload to suit the capabilities of the workers to the operations were essential. The workload that is appropriate for the worker will affect the efficiency of the work system in terms of productivity. On the other hand, if the workload is excessive, it can cause fatigue. As a result, overall job performance decreases. [1]-[2]

This research focuses on assessment of mental workload using the Satisfaction Survey form the NASA TASK LOAD INDEX (NASA-TLX) and compared with the brainwave of electroencephalography (EEG). The different types of the mental workload for assessment as follow: Evaluation of Posture Operation by RULA, Windows and Android operating systems and Manual. The RULA (Rapid Upper Limb Assessment) is the method of posture analysis that the software was developed for convenience applying in the field evaluation. Then the data was analyzed statistically. It promotes the application that useful for assessing the environment and work habits, leading to improvements in the work environment. [3]-[6]

II. Objective

1) Apply the mental workload using the evaluation form and the brainwave measuring instrument in the sample program test.

2) Study the relationship between psychological and brainwaves.

3) Set the experiment of mental workloads task that affect brainwaves.

III. Methods

Based on the comparison of mental workload from brainwave measurement for an ergonomic workload assessment, there are a number of steps to take. Therefore, the procedure of studying the comparison of mental workload from the measurement of brain waves according to the principles of ergonomics. It consists of steps to work. [7]-[9]

1) Review of the principles and theories related to the assessment of workload Ergonomics.
2) Study the use of the satisfaction survey form, TASK LOAD INDEX (NASA-TLX) and EEG
3) Review related research
4) Choose a sample work.
5) Two task load design
6) Work process tests
7) Evaluation of workload obtained from analysis of work process test and statistical analyses.
8) Performance summary

Flow Chart Steps to Study

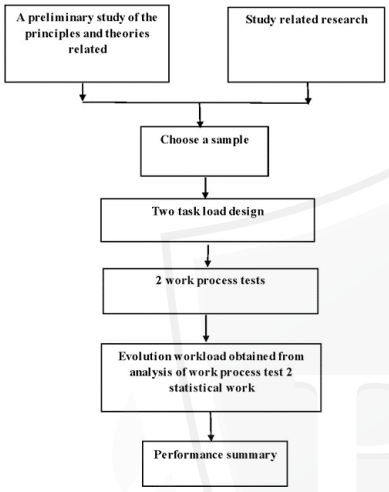
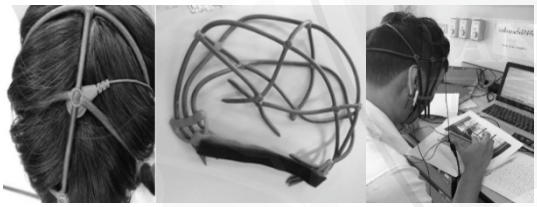


Fig. 1. shows the research process.



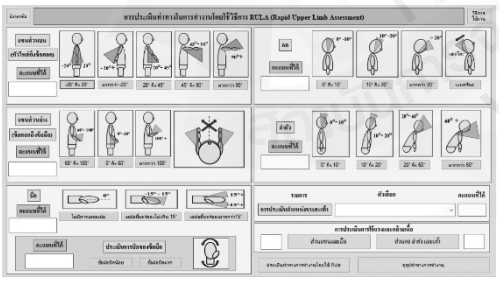


Fig. 2. Equipment Setting and The Menu of RULA Software Screen in Windows.

The Appling the NASA TASK LOAD INDEX (NASA-TLX) form and the brainwave (EEG)

3.1 The using of NASA-TLX form are divided into 6 dimensions as follows.

1. Mental Demand.
2. Physical Demand
3. Temporal Demand
4. Performance
5. Effort
6. Frustration

Procedure to use evaluation form NASA-TLX form

1. Set the weighted points in all 6 dimensions by setting the weighted values respectively. Feeling in different dimensions from 0-5, the sum of the weighted values must be equal to 15.
2. Make a grade based on the subjective level in each 6-dimensional assessment, from 0-20 points.
3. Get the points in each dimension, multiplying the weighted values of each dimension.
4. Bring the multiplication result together.
5. Take net sums divided by the weighted values net weight gain is already achieved.

3.2 Using a brainwave equipment (EEG)

1. Install the device with the tester.
2. Turn on the brainwave (EEG)
3. Open the program that will be used in conjunction with the EEG and set in computer input programs.
4. Test workload, then measured through a brainwave (EEG)
5. Analyze the results from graphs in the frequency range of interest.

IV. Tools

4.1 The different types of the mental workload for assessment as follow: Evaluation of Posture Operation by RULA, Windows and Android operating systems and Manual.

4.2 Satisfaction evaluation form, NASA TASK LOAD INDEX (NASA-TLX)

4.3 NeXus-10 Neuropsychological for EEG measurement

4.4 Camera and camcorder

4.5 Computer for statistical analysis

V. Results

5.1 Results of performance and quality assessment

5.1.1 Evaluating program performance in term of times

Table I shows the results of data collection and comparison between manual calculation compare with program in Windows and Android operating systems.

Activity	Manual	Windows	Android
Operation ○	12	10	10
Transport ⇨	0	0	0
Delay ▽	0	0	0
Inspection □	4	1	1
Storage D	0	0	0
Time (sec)	**203.89**	**71.48**	**64.41**

Data collection to compare data between manual calculation and using Rula SU program in Windows, Android operating systems. The RULA method was used to calculate score of posture analysis. From the manual calculation method, the average time spent evaluating the task was 203.89 seconds. The RulaSU in Windows operating systems average user experience is 71.48 seconds. RulaSU uses an average of 64.41 seconds for the Android operating system.

5.2 Evaluation of Statistical Time Data

When the time value is tested statistically. It was found that the distribution is normal and different.

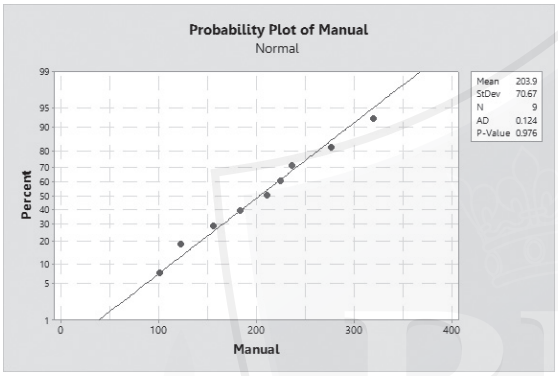


Fig. 3. Graph of time distribution of manual.

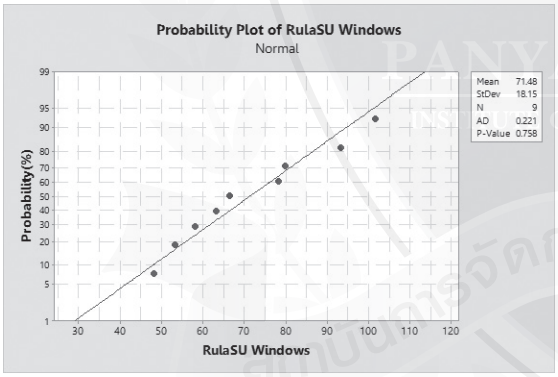


Fig. 4. Graph of time distribution of Windows operating systems.

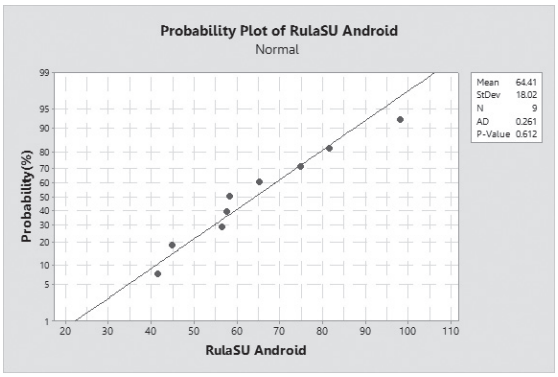


Fig. 5. Graph of time distribution of Android operating systems.

From the 3 graphs, it can be seen that the intersection is linear. The clustering characteristics are not clustered. And the distance between each point is almost the same. Three vehicles can be classified as Normal Distribution.

5.2.1. Test the hypothesis using the T-Test statistic.

-time correlation coefficient between manual and Windows operating system

Two-Sample T-Test and CI: Manual, RulaSU Windows

```
Two-sample T for Manual vs RulaSU Windows

                N   Mean  StDev  SE Mean
Manual          9  203.9   70.7       24
RulaSU Windows  9   71.5   18.2      6.1

Difference = μ (Manual) - μ (RulaSU Windows)
Estimate for difference:  132.4
95% CI for difference:  (80.9, 184.0)
T-Test of difference = 0 (vs ≠): T-Value = 5.44  P-Value = 0.000  DF = 16
```

Fig. 6. T-Test Analysis.

P-Value = 0.000, which is less than 0.05, rejecting the main assumption. It was concluded that the correlation coefficient of time data between manual and the Windows operating system to evaluate gestures using the RULA method was significantly different at the 95% confidence level.

Time correlation coefficient between manual and Android operating system

Two-Sample T-Test and CI: Manual, RulaSU Android

```
Two-sample T for Manual vs RulaSU Android

                N   Mean  StDev  SE Mean
Manual          9  203.9   70.7       24
RulaSU Android  9   64.4   18.0      6.0

Difference = μ (Manual) - μ (RulaSU Android)
Estimate for difference:  139.5
95% CI for difference:  (87.9, 191.0)
T-Test of difference = 0 (vs ≠): T-Value = 5.74  P-Value = 0.000  DF = 16
```

Fig. 7. T-Test Analysis.

P-Value = 0.000 which is less than 0.05, reject the main assumption. It was concluded that the correlation coefficient of time data between manual and Android operating system to evaluate gestures using the RULA method are significantly different at a 95% confidence level.

- time interval relationship value Windows operating system and Android operating system.

Two-Sample T-Test and CI: RulaSU Windows, RulaSU Android

```
Two-sample T for RulaSU Windows vs RulaSU Android

                N  Mean  StDev  SE Mean
RulaSU Windows  9  71.5   18.2      6.1
RulaSU Android  9  64.4   18.0      6.0


Difference = μ (RulaSU Windows) - μ (RulaSU Android)
Estimate for difference:  7.07
95% CI for difference:  (-11.10, 25.25)
T-Test of difference = 0 (vs ≠): T-Value = 0.83  P-Value = 0.420  DF = 15
```

Fig. 8. T-Test Analysis.

P-Value = 0.420, which is greater than 0.05, accept the main assumption. Thus, it was concluded that the temporal relationship between RulaSU and Windows operating system and the RulaSU implementation of Android operating system to evaluate gestures using RULA method were not significantly different. At a 95% confidence level

5.2.2. Assay Assumptions Using ANOVA One-Way Statistical Analysis

One-way ANOVA: Manual, RulaSU Windows, RulaSU Android

```
Method
Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor  Levels  Values
Factor       3  Manual, RulaSU Windows, RulaSU Android

Analysis of Variance

Source  DF  Adj SS  Adj MS  F-Value  P-Value
Factor   2  111111   55555    29.51    0.000
Error   24   45184    1883
Total   26  156294

Model Summary

      S    R-sq  R-sq(adj)  R-sq(pred)
43.3896  71.09%     68.68%      63.41%

Means
Factor          N   Mean  StDev      95% CI
Manual          9  203.9   70.7  (174.0,  233.7)
RulaSU Windows  9  71.48  18.15  (41.63, 101.33)
RulaSU Android  9  64.41  18.02  (34.56,  94.26)
Pooled StDev = 43.3896
```

Fig. 9. One-Way ANOVA.

P-Value = 0.000 which is less than 0.05, reject the main assumption. Therefore, the correlation coefficients of the three data types were significantly different at the 95% confidence level.

5.3 Results of psychological workload study using NASA TASK LOAD INDEX

1. Mental Demand
2. Physical Demand
3. Temporal Demand
4. Performance
5. Effort
6. Frustration

TABLE II
NASA-TLX SCORE OF MANUAL

Windows			
Topics	Average weight	Average raw score	Net score
Mental Demand	4.78	14.44	69.01
Physical Demand	0.56	7.11	3.95
Temporal Demand	1.78	9.33	16.59
Performance	3.78	13.78	52.05
Effort	1.44	9.33	13.48
Frustration	2.67	10.78	28.74
		Net score =	183.83
		Net weighted average score =	12.26

TABLE III
NASA-TLX SCORE OF ANDROID

Android			
Topics	Average weight	Average raw score	Net score
Mental Demand	4.33	13.33	57.78
Physical Demand	0.00	4.67	0.00
Temporal Demand	1.67	7.22	12.04
Performance	4.44	14.89	66.17
Effort	2.33	8.33	19.44
Frustration	2.22	8.89	19.75
		Net score =	175.19
		Net weighted average score =	11.68

TABLE IV
NASA-TLX SCORE OF ANDROID

Manual			
Topics	Average weight	Average raw score	Net score
Mental Demand	4.78	17.22	82.28
Physical Demand	1.00	9.44	9.44
Temporal Demand	2.22	12.00	26.67
Performance	0.44	9.00	4.00
Effort	3.33	14.89	49.63
Frustration	3.22	14.11	45.47
		Net score =	217.49
		Net weighted average score =	14.50

The results of mental workload evaluation are divided into the following methods.

- Evaluation of work postures using the RULA

TABLE V
AVERAGE NET SCORE OF WEIGHT AGIN OF ALL 3 METHODS OF 9 SUBJECTS

Method / Value	Manual	Windows	Android
Net weighted average score	14.50	1226	11.68

From the NASA-TLX, the weighted average net score. During the experiment, the 3 methods are mean as follows:

1. Manual method = 14.50
2. Windows operating system = 12.26
3. Android operating system = 11.68

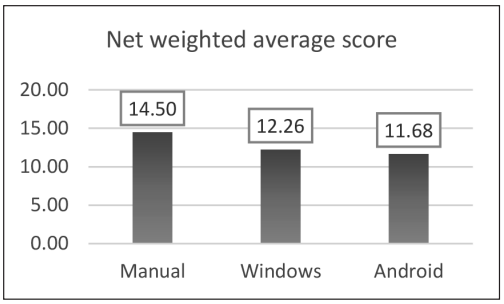


Fig. 10. the average of the net weighted scores for each of the 9 participants.

Based on the results of the 9 experiments, it was concluded that the method with the heaviest workload was Evaluate work postures using manual calculations. And the method with the minimum workload is How to use Android RulaSU program.

5.4 Results of the EEG Analysis Program (EEG)

TABLE VI
AVERAGE GAMMA WAVE UNDER NORMAL CONDITIONS AND WHILE EXPERIMENTING THROUGH ALL 3 METHODS

Method / person	baseline	Manual	Windows	Android
1	3.67	6.58	5.64	6.01
2	4.47	5.46	6.72	4.83
3	6.01	9.38	7.50	6.82
4	3.23	4.64	3.87	4.26
5	6.93	9.97	7.78	7.04
6	6.23	8.02	7.04	8.01
7	4.82	7.34	5.62	5.95
8	4.44	5.42	5.97	6.84
9	6.11	10.03	6.35	6.25
Mean	5.10	7.43	6.28	6.22

From the table, the results of the 9 brainstorming experiments show that Gamma

Amp. At normal and 4 experimental conditions have mean (Gamma Amp) 35-45 Hz as follows:

1. Baseline Normal Conditions = 5.10 μV
2. Manual calculation method = 7.43 μV
3. Windows operating system = 6.28 μV
4. Android operating system = 6.22 μV

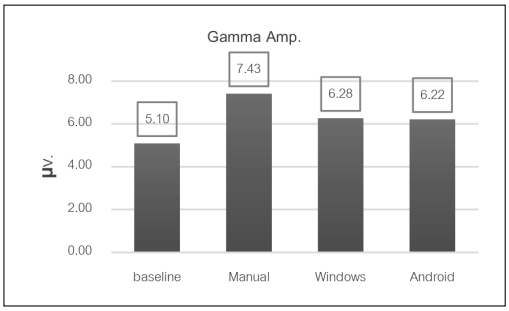


Fig. 11. the average Gamma Amp. of 9 people.

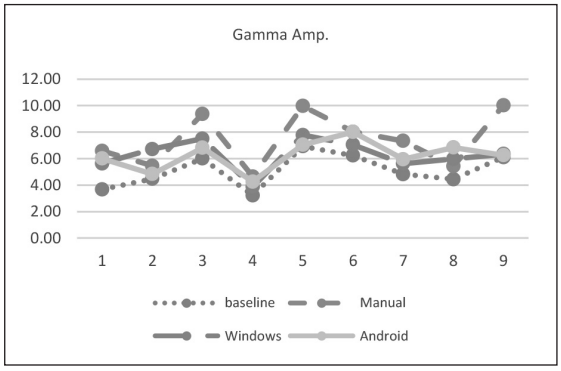


Fig. 12. Graph Average Gamma wave trend.

Based on the results of the 9 experiments, it was concluded that the method with the heaviest workload was evaluate work postures using manual calculations. and the method with the minimum workload is Android RulaSU program.

VI. CONCLUSION

6.1 Performance and Quality Assessment

- Evaluating program performance.

By comparing data between manual calculation methods with RulaSU applications, Windows operating systems, Android operating systems, it was found that using RulaSU, Windows and Android operating systems. There are fewer work procedures than the manual calculation method. Step 5 Time spent evaluating Windows workload is less than word methods. Manual 132.41 seconds and Android operating system time estimate are less than the 139.48 second manual calculation method. The result of the RulaSU program is a data acquisition window and summary that allows users to understand the results. Easier assessment So there are steps to get the data more convenient and take less time than manual calculating.

6.2 Statistical Time Evaluation

From the hypothesis test, One-Way ANOVA statistics were used to compare time correlation coefficients of application programs for estimating workload, various methods. In different ways of working, it found that time correlation coefficients between manual computation methods, RulaSU applications, Windows and Android operating is significantly different at 95% confidence level.

6.3 Workload Evaluation with NASA TASK LOAD INDEX (NASA-TLX) form

The experiment compares the work load of both people and by giving each job the same thing.

The method with the heaviest workload is Evaluate work postures using manual calculations. And the method with the minimum workload is Android RulaSU program.

6.4 Results of the analysis by the brainwave (EEG)

Based on the comparison of the work load, the work amplitude evaluation using the RULA method. The method with the heaviest workload is Evaluate work postures using manual calculations. and the method with the minimum workload is Android RulaSU program

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Benefit of Elastically Mounted Linear Damping Vibration Isolation for Transportation System

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Received: August 10, 2018/ Revised: September 10, 2018/ Accepted: October 2, 2018

***Abstract*—Aim of the research is to investigate benefit of supporting the damping element elastically. A single degree of freedom base excited vibration isolation system is focused for this study. Such the isolation system can be found in transportation system which its base is exciting. The improved vibration isolation system can help in reducing the damages caused from vibration to the transporting products. The proposed model has a damping element supported elastically by a spring. The damping force characteristic is assumed to be linear function of relative velocity across the damper. Two values of linear damping ratios were employed for investigation. The frequency response obtained from mathematical and numerical examinations are compared to experimental results. The frequency responses for the system with the relaxation spring are also compared to that with rigidly connected damper. Supporting the damping element elastically is found to reduce the vibration level for the high excitation frequencies in around 10 frequency decade from the natural frequency. The stiffness of supporting spring plays the important role in lowering the vibration level. Thus, it can be concluded that the vibration level of the products being transported can be reduced by supporting the damping element elastically.**

***Index Terms*—Base excited isolator, elastically supported damper, transportation vibration.**

I. Introduction

In road transportation system, it is known to have vibration transmitting from the vehicle to the products. This vibration can somehow cause to the products being damaged. In the case that the products are kind of delicate farm products, e.g., vegetables or fruits, the products could not be restored but be treated less value or waste. It is unlike the products in kind of machines which can be repaired and fixed. Thus, in the transportation procedure of farm products, the products should be protected in the proper ways.

By preventing vibration causing from unevenness of the road to the vehicle for which transmits to the products as consequential result, it is believed to reduce the amount of the products being damaged. One of equipment used for preventing vibration is known as a vibration isolator. The application of vibration isolator can be found in many places and in many forms as shown in Figure 1, for example, automotive suspension systems or shipping container suspension systems.



(a) (b)

Fig. 1. Various forms of vibration isolators.
(a) Automotive suspension system [1]
(b) Shipping container vibration isolator [2]

The example benefit of vibration isolator is to protect the farm products during transportation. There are numbers of publication mentioning about damage of fruits or farm products during transportation. O'Brien et al. [3] investigated the causes of fruit bruising on transport trucks. The investigation was carried out by using four types of farm products, i.e. peaches, pears, apricots and tomatoes, which were put in a separated-space container. The result showed significantly remarked for the severe level of vibration exceeding 1.0 g that the fruits in the second and third layers from the top were found damaged. Chonhenchob et al. [4] reported level of vibration from truck transportation in Thailand influencing to fresh fruit damage. They found that the physical

damage on the transporting fruits were noticeable. The major condition that caused fruit damage was found to be the poor packaging design which lack of vibration protection to the products.

By means of transportation vehicle, Ishikawa et al. [5] found that damage among fruits can be found varying on vibration frequencies. The key factor to the damage was focused on the type of transportation and vehicle used. It was added that between the trucks with leaf-spring suspension and air-ride suspension provide different vibration levels to the fruits. Zhou et al. [6] suggested in their study to apply the shock absorption treatments at the rear position of the truck floor to reduce the damage to the fruits. This is in corresponding to the study of Soleimani et al. [7] which mentioned about the effect of vibration level in truck bed and suspension to fruit damage. The leaf-spring suspension was found to produce greater vibration level compared to that for air-ride suspension. It is seen that by improving suspension characteristic for either vehicle suspension or packaging suspension can help providing fruits or farm products from damage.

Thus in this study, the ordinary linearly damped single degree of freedom base excited vibration isolator as shown in Fig. 2. (a) is applied by means of vibration isolator. It consists of a system mass, m, a suspension spring, k, and a damper, c. It is seen in Fig. 2. (a) that the damper is installed between the system mass and the base excitation. Such the model is called rigidly supported damper in this paper. Whereas the proposed elastically mounted damping system as shown in Fig. 2. (b) and 2 (c) is brought to the study for comparison in terms of vibration isolation performance. These two figures show that the damper is supported by the supporting spring k_r.

Fig. 2. (b) shows that the damper is installed between the system mass and the supporting spring whereas that in Fig. 2. (c) is installed between the base excitation and supporting spring. Theoretically, for the assumption with massless suspension spring and massless damper, these two models give the identical response. This is because spring and damper for either case experience the same force.

However, practically, the mass of suspension spring or the mass of damper cannot be neglected. Thus the responses for these two models are different. This is because the inertial force of either spring or damper. In this paper, the system is considered to have the damper installed between the system mass and the supporting spring as shown in Fig. 2. (b). Thus, mass of the damper is combined with the system mass and the damper becomes massless. As such, the supporting spring does not suffer the inertial force resulting from the damper.

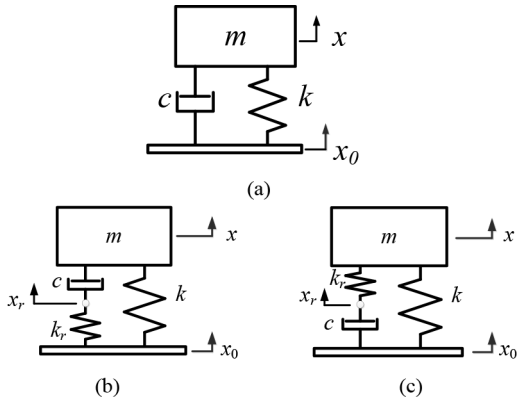


Fig. 2. Base excited vibration isolation models used in this paper.

In addition, number of the studies in vibration isolation performance for the elastically mounted damper can be found, for example in references [8], [9], [10] and [11]. Among these, Snowdon [9] showed the responses for the conventional base excited isolation system with linear damping in the comparison to those for system with relaxation spring in series to the damping. The inputs used were sinusoidal, step-like and pulse-like displacements. The author summarized that the overall response for the system with relaxation spring is better than that for the simple system.

The model of the vibration isolator using the elastically mounted damper was also examined by Carrella et al. [12]. The authors named such the model as the Zener model. They found that the effective damping is inversely varying to the value of damping coefficient. The effective damping tends to zero as the damping coefficient tends to infinity.

The Zener model was also brought to theoretical study by Silva et al. [13]. The original linear system spring was replaced by a nonlinear cubic spring. The response characteristic is also theoretically found to be beneficial on the transmissibility for the excitation frequencies high above the resonance frequency.

To this end, by employing the elastically mounted damper into the base excited vibration isolation system can be beneficial in reducing vibration level at frequencies high above the natural frequency. However, as for the author concerns, the response of the elastically mounted damper for the application of logistic or improving the supporting system for fruit transportation has not been found reported. Therefore, in this paper, the vibration response of the elastically mounted damper regarding the vibration isolation is studied in order to improve the vibration isolation performance of the supporting equipment.

II. Mathematical Modelling and Theoretical Aspect

Firstly, the models with linear damping are considered to demonstrate the effect of relaxation spring. The systems with linear damping are examined analytically for two frequency regions, i.e., when the excitation frequency is equal to the resonance frequency, $\omega = \omega_n$, and for the high excitation frequencies above the natural frequency, $\omega \to \infty$ or $\omega >> \omega_n$. In this study, the responses of the rigidly supported linear damper and the elastically supported linear damper are examined separately in the following sections.

A. Rigidly supported linear damper

Equation of motion for the mass of the SDOF model shown in Fig. 2. (a) can be formed as

$$\ddot{x} + 2\zeta\omega_n\left(\dot{x} - \dot{x}_0\right) + \omega_n^2\left(x - x_0\right) = 0 \tag{1}$$

where the natural frequency $\omega_n = \sqrt{\frac{k}{m}}$ and linear damping ratio $\zeta = \frac{c}{2\sqrt{mk}}$. x, $\dot{x}$ and $\ddot{x}$ represent displacement, velocity and acceleration of the system mass. $x_0$and $\dot{x}_0$ are displacement and velocity of the base excitation. The response for this system is well known as for the fundamental theory of mechanical vibration. Therefore, the description in response for this system is omitted in this paper.

The vibration response or the so called displace transmissibility function (DTF) for the system with rigidly supported damper can be obtained by solving equation of motion shown in (1). By assuming the single harmonic excitation, $x_0 = X_0\cos(\omega t)$, the solution for this model is well known and can be given as a function of frequency, ω, as

$$\left|\frac{X}{X_0}\right| = \sqrt{\frac{\omega_n^4 + \left(2\zeta\omega_n\omega\right)^2}{\left(\omega_n^2 - \omega^2\right)^2 + \left(2\zeta\omega_n\omega\right)^2}} \tag{2}$$

Equation (2) can be simplified for the case that $\omega = \omega_n$,

$$\left|\frac{X}{X_0}\right| = \sqrt{1 + \frac{1}{\left(2\zeta\right)^2}} \tag{3}$$

Equation (3) shows that, when $\omega = \omega_n$, the DTF level depends wholly on the value of damping ratio. The greater value of damping ratio results in the lower vibration level at this frequency.

For the case that $\omega >> \omega_n$, (2) can be approximated by

$$\left|\frac{X}{X_0}\right| = \frac{2\zeta\omega_n}{\omega} \tag{4}$$

Equation (4) shows that, the level of DTF reduces by 20 dB/decade as excitation frequency increases. However, it is seen and well known that the greater value of damping ratio results in the higher level of vibration response at high frequency. As also shown in Fig. 3. the greater value of damping ratio helps lowering the level of vibration at the resonance frequency as shown by an arrow (i). In contrast, it causes the higher vibration level at higher excitation frequencies, as indicated by an arrow (ii). This response characteristic can cause the damage to the product at excitation frequencies high above natural frequency. Thus, in order to maintain the lower level of vibration at around the resonance frequency, it is essential to eliminate unwanted characteristic of the linear damping at high excitation frequencies.

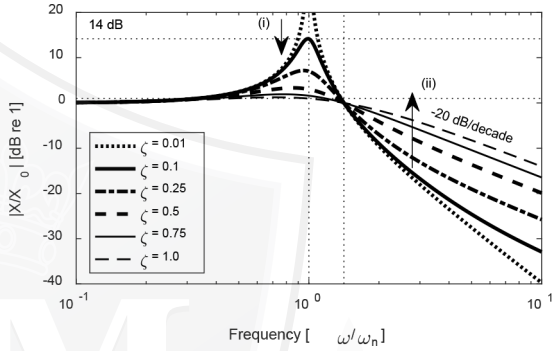


Fig. 3. Displacement transmissibility function for the rigidly mounted damping system.

B. Elastically mounted linear damper

The mathematical model for the elastically supported linear damper is obtained from the model shown in Fig. 2. (b). Theoretically, there is no difference by means of acting force on both the supporting spring and the damper for the models shown in Fig. 2. (b) and (c), as mentioned earlier. However, in order to be consistent to the experimental rig which the active damper is part of the system mass, thus the model in Fig. 2. (b) is employed. Equation of motion for the mass of the model shown in Fig. 2. (b) is given by

$$\ddot{x} + 2\zeta\omega_n\left(\dot{x} - \dot{x}_r\right) + \omega_n^2\left(x - x_0\right) = 0 \tag{5}$$

where $\dot{x}_r$ is the velocity of the connection point.

In addition, since the linear damper and spring experience the same force, therefore there is another first order equation for the force, i.e.

$$2\zeta\omega_n\left(\dot{x} - \dot{x}_r\right) = \kappa\left(x_r - x_0\right) \tag{6}$$

where x_0 is the displacement excitation and κ is the ratio between stiffness of the system spring k and the supporting k_r, i.e. $\kappa = \frac{k}{k_r}$.

The solutions for the elastically mounted damping system can be obtained by solving (5) and (6). For some aspect and convenience, (5) and (6) are written alternatively using relative velocity across the damper, i.e., $y_r = x - x_r$. Thus, (5) and (6) can be written as

$$\ddot{x} + \omega_n^2 x = \omega_n^2 x_0 - 2\zeta\omega_n \dot{y}_r \tag{7}$$

and

$$2\zeta\omega_n \dot{y}_r + \kappa y_r = \kappa x - \kappa x_0 \tag{8}$$

By assuming harmonic base excitation, $x_0 = X_0 \cos(\omega t)$, the solutions can be given by

$$\left|\frac{X}{X_0}\right| = \sqrt{\frac{(\kappa+1)^2 (2\zeta\omega_n\omega)^2 + \omega_n^4\kappa^2}{\left(\omega_n^2 - \omega^2 + \kappa\right)^2 (2\zeta\omega_n\omega)^2 + \kappa^2\left(\omega_n^2 - \omega^2\right)^2}} \tag{9}$$

For the case that $\omega = \omega_n$, (9) can be simplified to

$$\left|\frac{X}{X_0}\right| = \sqrt{\frac{(\kappa+1)^2}{\kappa^2} + \frac{1}{(2\zeta)^2}} \tag{10}$$

It is seen from (10) that, for the system with relaxation spring, the level of DTF at the natural frequency depends on both the value of damping ratio and stiffness ratio. The effects from these parameters are examined later in the following sections.

For the case that $\omega >> \omega_n$, (9) can be simplified to

$$\left|\frac{X}{X_0}\right| = \sqrt{\frac{(\kappa+1)^2 (2\zeta\omega_n)^2}{\left(\kappa - \omega^2\right)^2 (2\zeta\omega_n)^2 + \kappa^2\omega^2}} \tag{11}$$

Equation (11) also shows that the vibration response at excitation frequencies high above the natural frequency is dependent on both the value of damping ratio and the stiffness ratio. The effects for these parameters can be analyzed as follows.

1) The influence of linear damping ratio

The vibration behavior for the elastically supported damping system can be influenced by the value of damping ratio. The value of damping ratio can be considered to range from 0 to ∞. When damping ratio is equal to zero, the system becomes undamped system. This is identical to the system with $\kappa \to 0$. Equation (10) can result to infinity and (11) gives the result of undamped system.

In addition, the system mass is oscillating freely only on the suspension spring as shown in Fig. 2. (a). Thus the resonance frequency is the same as the natural frequency of the system is defined by

$$\omega_n = \sqrt{\frac{k}{m}} \tag{12}$$

When damping ratio approach infinity, $\zeta \to \infty$, the system mass can be considered oscillating on two springs, i.e., suspension and supporting spring as shown in Fig. 2. (b). This behavior is according to the results reported in [12]. The resonance frequency is then defined by

$$\omega_u = \sqrt{\frac{k + k_r}{m}} \tag{13}$$

The resulting frequency obtained from (13) is higher than that in (12). This means that the resonance frequency for the system with elastically supported damper is affected by the value of damping ratio. The variation of the resonance frequency can be illustrated as shown in Fig. 4. The resonance frequency shifts from ω_n to the higher frequency, ω_u, when value of damping ratio is about 0.5, as shown by an arrow (iii). In addition, when the value of damping ratio becoming much greater approaches infinity, the system becomes undamped vibration system on two parallel springs.

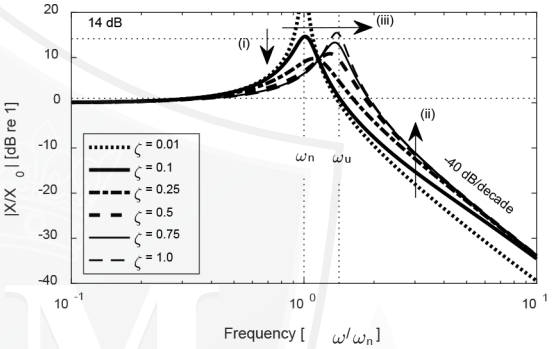


Fig. 4. Displacement Transmissibility Funtion for the elastically mounted damping system with $\kappa = 1$

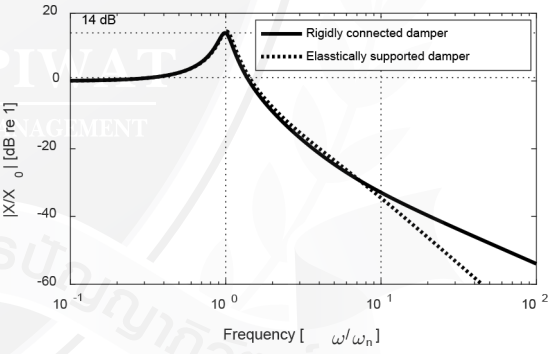


Fig. 5. Comparison of Displacement Transmissibility Funtion for the rigidly connected damper and elastically supported damper systems with $\zeta = 0.1$ and $\kappa = 1$

Furthermore, to show benefit of elastically supported damper, the responses for the system with damping ratio of 0.1 for those with rigidly connected damper and elastically supported damper which presented using the thick solid lines as seen in Fig. 3. and Fig. 4. are compared in Fig. 5. It is noticed that the peak levels are about the same at around 14 dB. But the level of vibration at the excitation frequencies higher than 10 are noticeable different. For that for rigidly connected damper reduces by 20 dB/decade, whereas that for elastically supported reduces by 40 dB/decade. This theoretically results show improvement of vibration isolation by supporting the damping element elastically.

2) The influence of stiffness ratio

The value of stiffness ratio influences the vibration response of the system by means of the level of vibration. There are two frequency regions which are affected, i.e., the resonance frequency and the frequencies higher than the natural frequency. The influence of the stiffness ratio to the vibration behavior is as shown in Fig. 6. for which the value of stiffness ratio can be considered to range between $0 < \kappa \ll \infty$.

For $\kappa \rightarrow 0$, this implies that $k_r \ll k$ or equivalent to no supporting spring ($k_r = 0$). The system mass is supported only by the suspension spring. This approach considers the system as the undamped system. The response in (10) becomes infinity and that for (11) becomes $\left|X/X_0\right| = 1/\omega^2$ which are the response for the undamped system.

For $\kappa \rightarrow \infty$, this implies that $k_r \gg k$ or equivalent to the rigidly support damper ($k_r = \infty$). Thus, this approach considers the system the same as the SDOF system.

The value of stiffness ratio is seen to directly influence the system damping. Fig. 6. shows the frequency response function for the system with constant damping ratio, $\zeta = 0.1$.

For the system with $\kappa = 0.1$, $k_r < k$, the system behaves similarly to the undamped SDOF system, i.e., the vibration level around the resonance frequency tends to infinity and the vibration in the high frequency region drops by 40 dB/decade. For the system with $\kappa = 100$, $k_r > k$, the system behaves similarly to the normal SDOF rigidly connected linear damping system.

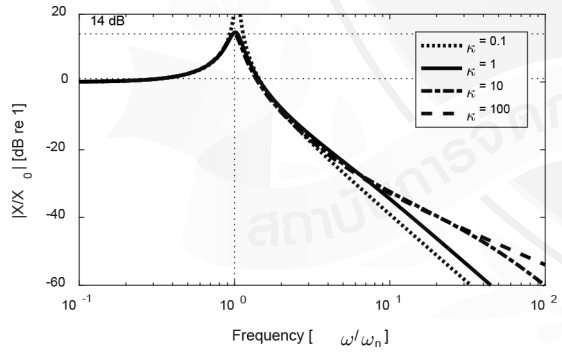


Fig. 6. Displacement transmissibility function for the elastically mounted damping system with $\zeta = 0.1$ for difference values of κ.

However, in this study, the influences of the damping ratio are examined experimentally. Two values of damping ratios were applied respectively whereas the value of stiffness ratio was kept constant.

III. Experimental Setup

The experimental rig is as shown in Fig. 7. The damping element was implemented by using the electromagnetic shaker LMS V101 as the active electrically controllable damper. The rig consisted of a system mass which was the mass of the shaker and additional mass, the suspension spring and the supporting spring. The base excitation was implemented by employing the B&K electromagnetic vibration exciter type 4808. The acceleration signals for both the system mass and the base excitation were captured using B&K 4508B accelerometers. The B&K Pulse LabShop was used to analyze the signals.

The base excitation was defined to be single frequency harmonic excitation. The sinusoidal signal was generated using a Tektronix CFG280 function generator. The amplitude of the signal was controlled to be the same for all applied frequencies which ranged from 6-200 Hz. The amplitude of the base excitation was controlled by means of input displacement. The acceleration signal of the base input was double integrated using the B&K Pulse LabShop. Amplitude of the harmonic base input was controlled to be 30, 40 and 50 μm respectively. Theoretically, the amplitude of the base excitation should not affect the vibration response for the linear vibration system. Thus, varying the excitation input was to ensure the linearity of the system.

In order to simulate the damping force characteristic, the acceleration signals were integrated to be signals of velocity. The integration process was implemented using an STM32 interface board as the schematic illustrated in Fig. 7. Only the signals at fundamental frequency were used. Signals in other frequencies and DC offset were filtered out using passive band pass filter. The integrated signals were then processed to be relative velocity between the system and the base excitation. The signal of relative velocity was then used as feedback signal to the damper. The signal was fed to the shaker amplifier which was acting as the adjustable damping coefficient. Then the amplified signal was fed to the shaker in order to produce the damping force. The process was applied to all excitation frequencies.

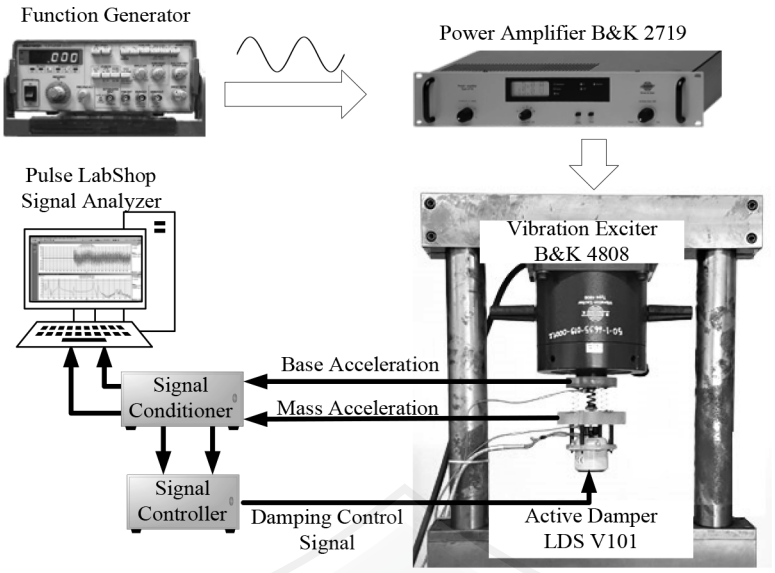


Fig. 7. Experimental rig and measuring components.

The damping was supported elastically by a spring as shown in Fig. 8. There were three suspension spring with the total stiffness of 3 kN/m. The spring stiffness of the electromagnetic shaker is 3.15 kN/m. Therefore the total stiffness for the system suspension was around 6.15 kN/m. Stiffness of the relaxation spring was around 6 kN/m. Thus the stiffness ratio, κ, was around 1.

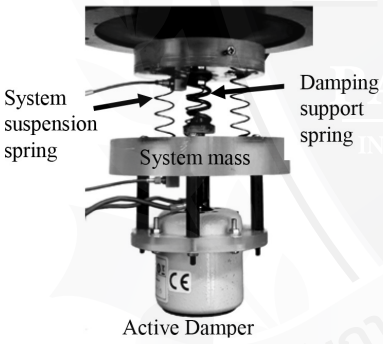


Fig. 8. Assembly of elastically mounted damping vibration isolation system.

Linearity of the experimental rig was carried out by testing on a rigidly mounted damper. Three levels of harmonic base excitation were applied respectively. The vibration response of the system was displayed in the form of displacement transmissibility function (DTF) which is the amplitude ratio between the base excitation and the absolute displacement. The level of vibration at around the resonance frequency was controlled to be around 14 dB as the DTF shown in Fig. 9. This vibration level refers to the value of damping ratio around 0.1.

Fig. 9. also shows that the difference in excitation amplitude did not affect the response of the system. Furthermore, by comparing the experimental results to the theoretical result, it is also seen that the experimental results follow the theoretical result smoothly. Therefore, the experimental rig was working linearly. Such the results assure that the results obtained from this experimental rig will not be affected by any non-linearity of the rig but the effects of supporting spring.

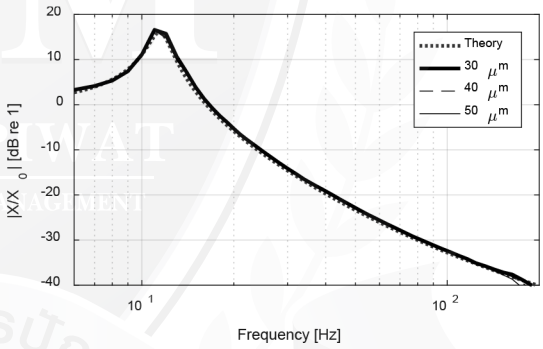


Fig. 9. Displacement Transmissibility Function for the system with rigidly mounted damping under three excitation amplitudes in comparison to the theoretical result.

IV. Results and Discussions

As the damping element was electronically controllable, the value of damping ratio was adjusted by referring to the level of DTF at the resonance frequency. The level of DTF at the resonance frequency was controlled to be the same for every level of base excitation and stiffness ratio. By doing so, the levels of DTF at the resonance frequency are equal as seen in Fig. 10. (a) and (b), the level of DTF was controlled to be around 14 dB and 9 dB, respectively. The corresponding value of damping ratios to the vibration level were 0.1 and 0.18, respectively. Therefore, the effects of elastically mounted damper can be seen for the high excitation frequencies.

The dotted lines in Fig. 10 (a) and (b) show the DTF for theoretical results of the rigidly mounted damper. These lines are used as the reference to examine the responses for the system with elastically supported damper. Thus the difference in level of DTF for the elastically mounted damper can be noticed.

The responses for the system with elastically supported damper are presented for three excitation amplitude, i.e., 30 μm, 40 μm and 50 μm. Similar to those for rigidly connected damper, difference levels of excitation amplitude were applied to check linearity of the system. It is seen that there is no significant variation in the responses caused from different excitation amplitudes. The responses from these three excitation amplitudes appear similarly for both values of applied damping ratio.

In Fig. 10. at the excitation frequencies higher than 100 Hz, the responses for the system with elastically supported damper are seen to reduce. Such the response characteristic is according to the theoretical examination shown in Fig. 5. The responses for both systems are in the similar level for around 10 frequency decade from the resonance frequency. After that, for the higher excitation frequencies, the responses for the elastically supported damper drop by 40 dB/decade.

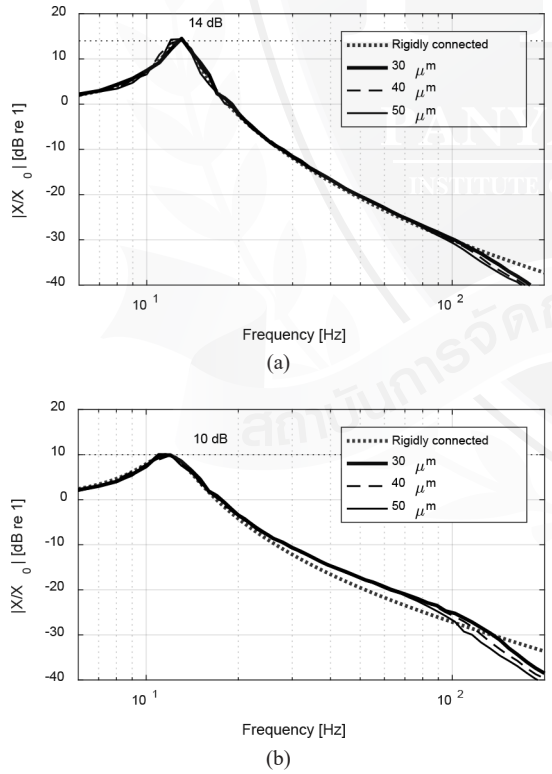


Fig. 10. Displacement Transmissibility Function for the elastically mounted damping system with $\kappa = 1$, (a) $\zeta = 0.1$ and (b) $\zeta = 0.16$.

To this end, the reduction in the vibration level at high frequencies are said to be the beneficial effects of having the elastically supported damper. Therefore, the application of elastically supported damper definitely helps to protect or isolate the system mass or the product from vibration caused by the exciting base. Nevertheless, the further study needs to be carried out in order to examine the important physical function of the supporting spring.

V. Conclusion

This study investigates the performance of the vibration isolator having elastically mounted linear damping. The theoretical results between the systems with rigidly mounted damping and elastically mounted damping were discussed and compared. The experimental investigation was performed to verify the benefit of the elastically mounted damping theoretically found. The experimental study was done by employing electromagnetic shaker to be as the active damper. The experimental results reveal the benefit of mounting the damping element elastically. The levels of vibration, for excitation frequencies 10 decade higher the natural frequency, are noticeable much lower than that for the rigidly connected damper. The experimental results show accordingly to those obtained theoretically which the level of vibration is found to be reduce by 40 dB per frequency decade. Thus, the level of vibration for the system with elastically supported damper can be much lower than that for the system with rigidly connected damper for the excitation frequencies much higher above the natural frequency. It can be said that the detrimental effects of the linear damper can be eliminated by supporting it elastically. Therefore, by having the damping element support elastically can help improve the vibration isolation performance of the isolation system and reduce damage caused from vibration at high excitation frequencies.

Acknowledgment

This work was funded by the National Science and Technology Development Agency (NSTDA), in a New Researcher Grants sponsored by Coordinating Center for Thai Government Science and Technology Scholarship Students (CSTS), Ministry of Science & Technology, Thailand.

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Capacity Planning of Aggregators and Multi-objective Optimization Approach to Optimal Data Transmission in Cloud Providers for Meteorological Sensor Network

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Received: February 15, 2019/ Revised: March 15, 2019 / Accepted: May 3, 2019

***Abstract*—To predict weather precisely, meteorologists need to collect and analyze meteorological data from wireless sensor devices installed in different areas. Today, cloud computing provides efficient storage and processing tasks for large-scaled sensor data. However, wireless sensors are constrained with bandwidth to transmit data to the cloud. Therefore, we propose a system model called cloud-based meteorological sensor network with aggregator approach which combines data from sensors and forwards to the cloud with better bandwidth. In this paper, the two main problems are considered for proposed system model. First, optimization approach to capacity planning of aggregators is addressed to obtain optimal number of aggregators for providing enough services to sensor data while reducing high investment. Second, optimal data transmission (ODT) algorithm based on multi-objective optimization approach is also proposed to minimize cost for provisioning resources and delay for transferring and processing when data from aggregators are allocated to multiple cloud providers. Then, the extensive numerical studies are performed for each problem. The numerical results provide not only optimal number of aggregators with the minimum total cost but also optimal data transmission from aggregators to the cloud with the minimum total cost and delay for the proposed system model.**

***Index Terms*—Cloud Computing, Capacity Planning of Aggregators, Multi-objective Optimization Approach, Wireless Sensor Network.**

I. Introduction

In recent years, wireless sensor networks have attracted a lot of attention by many researchers. A wireless sensor network (WSN) combines hundreds or even thousands of tiny and resource constrained sensor devices that are interconnected wirelessly and able to collect the data from surroundings [1]. WSNs have been employed in many applications such as transport monitoring, weather forecasting, military monitoring, agricultural monitoring, and healthcare monitoring. Among wide applications in WSN, weather forecasting has been played a critical part in people's lives to provide early warning for natural disasters such as landslides, water flooding, catastrophic earthquake, and volcanic eruption, etc. To predict weather precisely, meteorologists need to deploy a number of sensor nodes in different areas to periodically measure meteorological data such as temperature, humidity, wind speed, rainfall, atmospheric pressure, seismic wave, etc and transmit the data to the database server provided by meteorologists in order to process and report weather information to people. However, the volume of sensor data can be rapidly increased so that it will become big data in the future. As a result, the traditional database applications with limited capacity of storage and processing power cannot store and process such a large amount of data [2].

To resolve this issue, cloud computing is a potential solution which provides a plenty of storage and processing power resources without purchasing any hardware or physical infrastructure [3]. By applying cloud computing, a large amount of data from sensors can be stored and processed in an efficient manner. Then, the meteorologists can access the processed data from cloud providers and provide people with useful weather information. However, wireless sensor network has bandwidth constraint and could incur to network latency for the direct transmission of data to the cloud over remote distance [4].

To overcome this constraint, we propose a system model called cloud-based meteorological sensor

network with aggregator approach. In the system, the aggregator approach provides aggregators which perform like buffering servers by collecting the data from wireless sensor network and forwarding to the cloud with faster bandwidth. With the use of aggregator approach, it can deal with bandwidth limitation occurred in sensors and improve the scalability of the proposed system.

The major contributions in this paper are presented below. First, optimization approach to capacity planning of aggregators for the proposed system model is addressed to determine the optimal number of aggregators with the minimum total cost. Second, optimal data transmission (ODT) algorithm based on multi-objective optimization approach is also proposed to allocate the data from aggregators to various commercial cloud providers with the minimum cost for resource provisioning and delay for transferring and processing. We also perform extensive numerical studies to evaluate the performance of proposed ODT algorithm. The results show that ODT algorithm can provide the optimal solution for transmitting data from aggregators to cloud providers while the total cost and delay is minimized.

II. Related Works

Recently, previous researchers have focused on wireless sensor network in various applications. A design level framework using WSN is proposed for developing smart environment by monitoring natural disasters [5]. Moreover, WSN system is deployed in agricultural field to monitor agricultural parameters such as air temperature, air humidity, soil temperature, soil water content and leaf wetness [6]. Besides, system architecture for smart healthcare based on WSN is proposed to provide remote health monitoring [7]. Furthermore, an intelligent transportation system based on WSN is illustrated for traffic monitoring and road safety management [8]. However, the aforementioned proposed systems transmit the data to the traditional database server and did not take into consideration the limitation of storage and processing capacities in database server. As a result, it can overload when the arrival of data from sensors is increasingly growing. Under overload, it may suffer excessive data loss and processing delay. Finally, it can seriously affect the timeliness of delivery of important information or results to users.

To deal with this issue, the development of cloud computing technology enables to store and process a large amount of data since it can offer abundant resources of storage and processing power. There are many research works benefit from cloud computing resources in different fields such as multimedia surveillance system, vehicular adhoc networks (VANET) technology, and smart environment monitoring as cited in [9], [10], and [11]. In this work, we apply the benefits of cloud computing resources for meteorological sensor network.

Although cloud computing can provide abundant storage and processing power resources, it is likely to occur serious network latency when wireless sensors with bandwidth constraint to transfer data to the cloud. To overcome this challenge, the concept of aggregator approach as buffer is introduced in some research works. A one-layer aggregation-based architecture is proposed in which aggregators are deployed to aggregate data from smart meters and send the aggregated data to relay nodes [12]. In patient monitoring, aggregator agent is applied to transmit the patient's parameters from body sensors to the cloud for storing and processing [13]. Similarly, typical wireless body area network (WBAN) architecture is proposed where body control unit is applied which serves as aggregator approach to collect the data from sensors and upload to remote server for remote continual healthcare monitoring [14].

Based on the works in [12], [13], and [14], this paper proposes a system model of cloud-based meteorological sensor network by exploiting aggregator approach. The aggregator approach can provide aggregators or buffers to reduce network latency for data transmission by bridging between sensors and cloud. In proposed system model, optimization approach to capacity planning of aggregators is applied to obtain the optimal number of aggregators with the minimum cost. Moreover, multi-objective optimization approach is also applied to achieve optimal data transmission from aggregators to the cloud with the minimum cost and delay.

To the best of knowledge, there are currently no works that address optimization approach to capacity planning of aggregators and multi-objective optimization approach to optimal data transmission in cloud providers in the field of wireless sensor network (WSN) especially for meteorological application.

II. Proposed System Model

In this section, the proposed system model of cloud-based meteorological sensor network is presented in Fig. 1.

This system model is mainly designed for one area where a set of several sensor devices are installed such as humidity sensor, temperature sensor, seismic sensor, vibration sensor, sound sensor, water sensor, etc. After deployment, all sensor nodes are fixed or stationary which can detect environmental data such as wind speed, wind direction, temperature, precipitation, soil moisture, barometric pressure, etc. A cluster head (CH) is then selected from other sensors based on higher computer power, storage space energy, and communication range criteria compared to others. Then, sensors can periodically send the data to CH via wireless direct connection using TDMA (Time

Division Multiple Access) protocols as it can prevent collision and retransmission of data [15]. The CH packages the data into the data packets and transmits the data packets per unit of time to the external aggregators via ZigBee network technology, which consumes very little energy, so that the lifetime of the sensor network can be improved. [16].

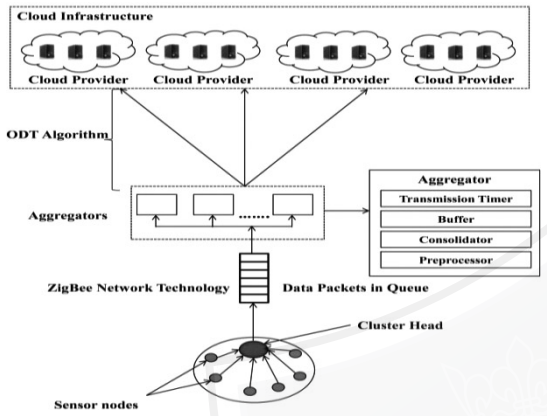


Fig. 1. System model of cloud-based meteorological sensor network.

After that, the aggregators collet the incoming data packets from sensors and perform step by step procedure. First, each aggregator preprocesses the data packets by eliminating erroneous and redundant data in order to improve accuracy level. Next, the processed data packets are aggregated as a single bucket by a consolidator to reduce the amount of data transmission and then stored in buffer. Then, a transmission timer in each aggregator transmits the consolidated data buckets from buffer to the cloud infrastructure by setting a specific time. Here, optimal data transmission (ODT) algorithm is implemented between aggregators and cloud infrastructure. In the cloud infrastructure, there are a number of cloud providers who offer different capacity of resources (i.e., storage, processing power, and network bandwidth) and also charge different prices for utilization of resources to consumers. Here, we need to pay attention that it can encounter higher cost for resource utilization and latency for transferring and processing when the aggregators randomly transfer data to cloud providers. To tackle this problem, the proposed ODT algorithm can make decision based on the optimal solution from multi-objective optimization approach to allocate data from aggregators to cloud providers with the minimum cost and delay.

Finally, the cloud infrastructure processes the data buckets from aggregators and produces the weather report including intensity, measurements, risk levels, maps, and images, etc. The warning system is also installed in the cloud to immediately alert meteorologists for disasters. Because of the alert, weather information can be noticed and transmitted to the public for disaster preparation.

IV. Problem Formulation

Since the proposed system model shown in Fig. 1 is designed by aggregators and cloud computing, we address and formulate the two main problems for capacity planning of aggregators to minimize total cost and optimal data transmission algorithm to minimize total cost and delay for data allocation from aggregators to the cloud.

A. Capacity Planning of Aggregators

First, the problem of capacity planning of aggregators is taken into account to be formulated. Since the aggregators are installed in the proposed system model, capacity planning of aggregators is an important issue for meteorologists that how many aggregators are required to handle the fast growing data from sensors while the investment of aggregators is minimized. More precisely, sensors continuously generate data so that it can be difficult to use only single aggregator for processing such exponential growth of data. Therefore, multiple aggregators need to be purchased from third party providers (e.g., Internet Service Providers (ISPs) or cloudlet providers [17]) to provide better system performance. However, applying multiple aggregators can lead to very high investment. Hence, it is important to determine the optimal number of aggregators in order to tradeoff between more aggregators for providing good service and fewer aggregators for reducing high investment.

To solve this issue, multi-server queuing theory is applied to formulate the problem for capacity planning of aggregators. Firstly, the nomenclatures are defined. It is assumed that the average arrival rate of data packets λ from cluster head to aggregators per unit of time is constant. In this case, data packets from cluster head to aggregators are queued based on the discipline of first-come-first-served (FCFS). The average service rate of data packets μ served by each aggregator per unit of time is also constant because it is assumed that the cluster head packages data packets to be the same size. Here, the service rate μ is higher than the arrival rate λ in order to become steady system. Let A denotes the number of aggregators. Let C_s denotes the service cost for purchasing and installing each aggregator. Let C_w denotes the waiting cost of each data packet in queue by assigning reasonable prices. In this case, the sum of these two costs must be minimized to obtain the optimal number of aggregators by trading off between providing higher service to reduce waiting time of data packets and lower service to reduce investment of aggregators.

According to the nomenclatures, we formulate the problem for capacity planning of aggregators using multi-server queuing theory below.

$$\text{Minimize: } C_{total} = AC_s + C_w\left[\frac{1}{(A-1)!}\left(\frac{\lambda}{\mu}\right)^A \frac{\mu\lambda}{(\mu A-\lambda)^2}\right]\left[\frac{1}{\left(\sum_{n=0}^{n=A-1}\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right)+\frac{1}{A!}\left(\frac{\lambda^A}{\mu}\right)\left(\frac{A\mu}{A\mu-\lambda}\right)}\right]+\frac{\lambda}{\mu} \quad (1)$$

$$\text{Subject to: } \frac{1}{\lambda}\left\{\left[\frac{1}{(A-1)!}\left(\frac{\lambda}{\mu}\right)^A \frac{\mu\lambda}{(\mu A-\lambda)^2}\right]\left[\sum_{n=0}^{n=A-1}\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n+\frac{1}{A!}\left(\frac{\lambda}{\mu}\right)^A\frac{A\mu}{A\mu-\lambda}\right]^{-1}+\frac{\lambda}{\mu}\right\} \le S_{max} \quad (2)$$

$$\frac{1}{\lambda}\left\{\left[\frac{1}{(A-1)!}\left(\frac{\lambda}{\mu}\right)^A \frac{\mu\lambda}{(\mu A-\lambda)^2}\right]\left[\sum_{n=0}^{n=A-1}\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n+\frac{1}{A!}\left(\frac{\lambda}{\mu}\right)^A\frac{A\mu}{A\mu-\lambda}\right]^{-1}\right\} \le W_{max} \quad (3)$$

$$\frac{\lambda}{A\mu} < 1 \quad (4)$$

$$A \in \{0,1,\ldots\} \quad (5)$$

The objective function in (1) shows minimizing the total cost including service cost and waiting cost for obtaining the optimal number of aggregators. In constraint (2), aggregators A serve the data packets in the system must not exceed the maximum service time threshold S_{max}. In constraint (3), the time taken of each data packet waiting in queue to serve by aggregators A must not exceed the maximum waiting time threshold W_{max}. In constraint (4), it controls that the usage of aggregators must be less than 1 in order to form a stable system. In constraint (5), decision variables are required to take integer values for the number of aggregators.

With the help of optimization approach, it can determine the optimal number of aggregators with the minimum total cost.

B. Optimal Data Transmission Algorithm

After knowing the optimal number of aggregators, the data buckets from each aggregator need to be transferred to cloud infrastructure for storing and processing. Since different cloud providers in infrastructure have different amount of resources and prices for resource utilization, it is a serious issue to choose cloud providers in order to minimize total cost for provisioning resources and delay for transferring and processing. In order to optimally transfer data buckets from aggregators to cloud providers with the minimum cost and delay, optimal data transmission (ODT) algorithm is developed by applying multi-objective optimization model which formulates the problem involving more than one objective function and enables to optimize simultaneously.

To formulate the multi-objective optimization model, the nomenclatures are first defined. Let $A = \{a_1, a_2, \ldots, a_{last}\}$ denotes a set of aggregators. Let n_a denotes the number of data buckets from each aggregator. Let $d_a^{(s)}$ denotes the size of each data bucket, $d_a^{(p)}$ denotes the processing power required by each data bucket, and $d_a^{(n)}$ denotes the network bandwidth required by each data bucket from each aggregator. Let $J = \{j_1, j_2, \ldots, j_{last}\}$ denotes a set of cloud providers. Let $t_j^{(s)}$ denotes the capacity of storage, $t_j^{(p)}$ denotes the processing power, and $t_j^{(n)}$ denotes the network bandwidth. Let $c_j^{(s)}$ denotes the unit cost for storage, $c_j^{(p)}$ denotes the unit cost for processing power, and $c_j^{(n)}$ denotes the unit cost for network bandwidth charged by each cloud provider. Let X_{aj} denotes the decision variable which indicates that aggregators a transfer data buckets to cloud providers j. Based on these nomenclatures, multi-objective optimization model is formulated as follow.

Minimize:

$$\sum_{a\in A}\sum_{j\in J}\left\{\left(c_j^{(s)}\times X_{aj}\right)+\left(c_j^{(p)}\times X_{aj}\right)+\left(c_j^{(n)}\times X_{aj}\right)\right\}, \sum_{a\in A}\sum_{j\in J}\left\{\left(\frac{d_a^{(s)}\times X_{aj}}{t_j^{(n)}}\right)+\left(\frac{d_a^{(s)}\times X_{aj}}{t_j^{(p)}}\right)\right\} \quad (6)$$

$$\text{Subject to: } \sum_{j\in J} X_{aj} = n_a, \forall a \in A \quad (7)$$

$$\sum_{a\in A}\left(d_a^{(s)}\times X_{aj}\right) \le t_j^{(s)}, \forall j \in J \quad (8)$$

$$\sum_{a\in A}\left(d_a^{(p)}\times X_{aj}\right) \le t_j^{(p)}, \forall j \in J \quad (9)$$

$$\sum_{a\in A}\left(d_a^{(n)}\times X_{aj}\right) \le t_j^{(n)}, \forall j \in J \quad (10)$$

$$X_{aj} \in \{0,1,\ldots\}, \forall a \in A, j \in J \quad (11)$$

The formulation in (6) is multi-objective optimization to minimize total cost (for storage, processing power, and network bandwidth resources) and total delay (for data transmission and processing) for allocating data buckets from aggregators to cloud providers. The constraint in (7) ensures that the number of data buckets from aggregators is allocated to cloud providers. The constraints in (8)-(10) ensure that the resources of storage, processing power, and network bandwidth required by data buckets from all aggregators must not exceed the capacity of resources offered by each cloud provider. The last constraint in (11) specifies that the decision variable allocates non-negative integer number of data buckets from aggregators to cloud providers.

Using multi-objective optimization approach, the proposed ODT algorithm can minimize the total cost and delay for transferring data buckets from aggregators to cloud providers.

V. Parameter Setting And Numerical Studies

In this section, we define parameters and perform numerical studies for capacity planning of aggregators and optimal data transmission algorithm.

A. Capacity Planning of Aggregators

The average arrival rate of data packets λ is 160 data packets per hour from cluster head to aggregators. The average service rate of each aggregator μ can process 50 data packets per hour. The service cost C_s for purchasing and installing each aggregator is defined as \$10. The waiting cost of data packets in queue C_w is defined as \$15. In this case, an assumption is made that the waiting cost of data packets is higher than the service cost of aggregators to avoid the long delay in queue since the weather data is important in people's daily lives. The maximum service time threshold S_{max} is 300 sec per data packet while the maximum waiting time threshold W_{max} is 120 sec per data packet. The formulations in Section IV (A) can be solved on the basis of these parameters and the optimum number of aggregators can also be evaluated.

Fig. 2. shows the performance analysis of total cost, service cost, and waiting cost compared to the number of aggregators.

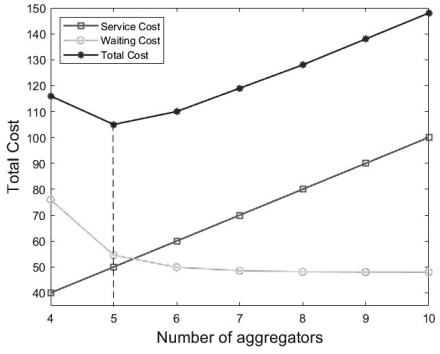


Fig. 2. Total cost compared to number of aggregators.

In Fig. 2, it is calculated using the formula $\left(\left(\lambda / \mu\right)+1\right)$ to estimate the minimum number of aggregators (i.e., 4 aggregators) required for the system and then increased to 10 aggregators. As long as the number of aggregators is increased, the service cost is getting higher while the waiting cost is getter lower. It is clear to see that the optimal number of aggregators is 5 with the minimum total cost of \$105. At this optimal point, the waiting cost of data packets in the system is lessened compared to the level of 4 aggregators.

B. Optimal Data Transmission Algorithm

As we obtained the optimal number of five aggregators (i.e., $|A|= 5$) by using multi-server queuing theory, each aggregator needs to transfer data buckets to cloud providers for storage and processing. Suppose that there are different number of data buckets in each aggregator, e.g., na = $\{n_1 = 35, n_2 = 30, n_3 = 20, n_4 = 25, n_5 = 35\}$. The size of each data bucket from all aggregators is assumed as 20 (MB). Since the size of each data bucket is the same, the same processing power required by each data bucket from all aggregators is also assumed as 15 (CPU-hours) and the same network bandwidth required by each data bucket from all aggregators is also assumed as 6.9 (MB/sec).

In the proposed system model, we assume that the cloud infrastructure is composed of four cloud providers (i.e., $|J| = 4$). The storage capacity offered by cloud providers j_1 and j_3 are 1000 (GB), j_2 is 2000 (GB), and j_4 is 500 (GB), respectively. The processing power offered by cloud providers j_1 and j_4 are 1500 (CPU-hours), j_2 is 1200 (CPU-hours), and j_3 is 3000 (CPU-hours), respectively. For network bandwidth, all aggregators must share the bandwidth offered by each cloud provider. Cloud provider j_1 offers 375 (MB/sec), j_2 offers 500 (MB/sec), j_3 offers 625 (MB/sec), and j_4 offers 250 (MB/sec) to all aggregators a_1 to a_5. Cloud providers also define different prices for storage, processing power, and network bandwidth resources per each data bucket. For storage resource, cloud provider j_1 and j_3 charge \$0.70, j_2 charges \$0.80, and $j_4$charges \$0.60, respectively. For processing power resource, cloud provider j_1 and j_4 charge \$0.50, j_2 charges \$0.40, and j_3 charges \$0.60, respectively. For network bandwidth resource, cloud provider j_1 charges \$0.25, j_2 charges \$0.30, j_3 charges \$0.35, and j_4 charges \$0.20, respectively. With these parameters, the multi-objective formulations in Section IV (B) can be solved and numerical studies are performed in the following subsections.

1. Weighted Sum Method

In order to solve multi-objective optimization problem, weighted sum method is applied. The general idea of this method is to associate each

objective function with a weighting coefficient and minimize the weighted sum of each objective [18]. In this way, the original multi-objective problem is transformed into a single objective one and Pareto optimal solution can be obtained. Here, changing weights can provide different Pareto optimal solutions to decision maker. In this case, ODT algorithm is decision maker. Then, the ODT algorithm can choose the reasonable weights which provide the most preferred optimal solution among others. With weighted sum method, the form of multi-objective optimization in (6) is converted into single objective optimization as follow.

Minimize:

$$\sum_{a\in A}\sum_{j\in A}\left[w_1\left\{\left(c_j^{(s)}\times X_{aj}\right)+\left(c_j^{(p)}\times X_{aj}\right)+\left(c_j^{(n)}\times X_{aj}\right)\right\}+w_2\left\{\left(\frac{d_a^{(s)}\times X_{aj}}{t_j^{(n)}}\right)+\left(\frac{d_a^{(s)}\times X_{aj}}{t_j^{(p)}}\right)\right\}\right] \quad (12)$$

Subject to: (7), (8), (9), (10), (11)

TABLE I
SET OF PARETO OPTIMAL SOLUTIONS BY USING WEIGHTED SUM METHOD

Weights (w_1, w_2)		(-,1)	(0.1,0.9)	(0.2,0.8)	(0.3,0.7)	(0.4,0.6)	(0.5,0.5)	(0.6,0.4)	(0.7,0.3)	(0.8,0.2)	(0.9,0.1)	(1,-)
Pareto Optimal Solutions	$X_{a_1j_1}$	35	0	35	35	35	35	35	35	35	32	32
	$X_{a_1j_2}$	0	15	0	0	0	0	0	0	0	0	0
	$X_{a_1j_3}$	0	20	0	0	0	0	0	0	0	0	0
	$X_{a_1j_4}$	0	0	0	0	0	0	0	0	0	3	3
	$X_{a_2j_1}$	5	0	5	5	5	5	5	5	5	0	0
	$X_{a_2j_2}$	0	0	0	0	0	0	0	0	0	0	0
	$X_{a_2j_3}$	0	30	0	0	0	0	0	0	0	0	0
	$X_{a_2j_4}$	25	0	25	25	25	25	25	25	25	30	30
	$X_{a_3j_1}$	0	0	0	0	0	0	0	0	0	0	0
	$X_{a_3j_2}$	20	20	20	20	20	20	20	20	20	20	20
	$X_{a_3j_3}$	0	0	0	0	0	0	0	0	0	0	0
	$X_{a_3j_4}$	0	0	0	0	0	0	0	0	0	0	0
	$X_{a_4j_1}$	0	23	0	0	0	0	0	0	0	0	0
	$X_{a_4j_2}$	25	2	25	25	25	25	25	25	25	17	17
	$X_{a_4j_3}$	0	0	0	0	0	0	0	0	0	8	8
	$X_{a_4j_4}$	0	0	0	0	0	0	0	0	0	0	0
	$X_{a_5j_1}$	10	0	10	10	10	10	10	10	10	22	22
	$X_{a_5j_2}$	25	35	25	25	25	25	25	25	25	13	13
	$X_{a_5j_3}$	0	0	0	0	0	0	0	0	0	0	0
	$X_{a_5j_4}$	0	0	0	0	0	0	0	0	0	0	0
Total cost & delay		219.63	29.18	49.71	69.74	89.78	109.82	129.85	149.89	169.93	189.20	216.77

The objective function in (12) is formulated based on weighted sum method where w_1 defines the first weighting coefficient for total cost and w_2 defines second weighting coefficient for total delay. The constraints in (7) – (11) are addressed again. Then, GAMS/CPLEX solver [19] is applied to solve the formulations in (12), (7)-(11) and obtain a set of Pareto optimal solutions with different weights as given in Table I.

Since the objective function (the sum of total cost and total delay) in (12) is to be minimized, it is highlighted that the reasonable weights (w_1 = 0.1, w_2 = 0.9) yield the most preferred optimal solution with the minimum total cost and delay (i.e., 29.18). According to the optimal solution provided by weights (w_1 = 0.1, w_2 = 0.9), ODT algorithm can make decision that aggregator a_1 transmits 15 data buckets to cloud provider j_2 and 20 data buckets to cloud provider j_3, a_2 transmits 30 data buckets to cloud provider j_3, a_3 transmits 20 data buckets to cloud provider j_2, $a_4$transmits 23 data buckets to cloud provider j_1 and 2 data buckets cloud providerj_2, and a_5 transmits 35 data buckets to cloud provider j_2.

2. Brute Force Search Algorithm

To evaluate the optimal solution provided by weights (w_1 = 0.1, w_2 = 0.9), brute force search algorithm is applied and numerical results are studied. The brute force search algorithm exhaustively finds every feasible solution until the optimal solution is found. Firstly, each possible solution is checked whether it is satisfied for all constraints or not. If the solution violates one constraint, it can be defined infeasible solution. Then, another possible solution is checked again. If the solution is satisfied for all constraints, it can be defined feasible solution and this solution is calculated into objective function. Then, different total cost and delay values will be obtained from different feasible solutions. Finally, the optimal solution can be chosen based on the objective either maximize or minimize. Table II shows the evaluation of optimal solution by brute force search algorithm.

TABLE II
EVALUATION OF OPTIMAL SOLUTION BY BRUTE FORCE SEARCH ALGORITHM

Decision Variables	Feasible Solutions				
$X_{a_1 j_1}$	0	35	15	20	20
$X_{a_1 j_2}$	15	0	0	0	0
$X_{a_1 j_3}$	20	0	0	0	0
$X_{a_1 j_4}$	0	0	20	15	15
$X_{a_2 j_1}$	0	5	0	0	0
$X_{a_2 j_2}$	0	0	0	0	0
$X_{a_2 j_3}$	30	25	25	25	30
$X_{a_2 j_4}$	0	0	5	5	0
$X_{a_3 j_1}$	0	0	0	0	0
$X_{a_3 j_2}$	20	20	20	10	20
$X_{a_3 j_3}$	0	0	0	10	0
$X_{a_3 j_4}$	0	0	0	0	0
$X_{a_4 j_1}$	23	0	0	0	0
$X_{a_4 j_2}$	2	25	25	25	25
$X_{a_4 j_3}$	0	0	0	0	0
$X_{a_4 j_4}$	0	0	0	0	0
$X_{a_5 j_1}$	0	10	10	10	0
$X_{a_5 j_2}$	35	25	25	25	25
$X_{a_5 j_3}$	0	0	0	0	0
$X_{a_5 j_4}$	0	0	0	0	10
Total cost & delay	29.18	29.32	29.54	29.48	29.51

In Table II, it is highlighted and proven the optimal solution which provides the minimum total cost and delay (i.e., 29.18) compared to the ones from other feasible solutions. In addition, this optimal solution is also similar to the one obtained by GAMS/CPLEX solver.

3. Sensitivity Analysis

Furthermore, sensitivity analysis is also performed to study how sensitive the optimal solution obtained by weights ($w_1 = 0.1, w_2 = 0.9$) by changing one input parameter while keeping other parameters constant. Table III shows the numerical results for sensitivity analysis.

In Table III, the parameters for size of data buckets, processing power of data buckets, bandwidth of data buckets, storage capacity of cloud providers, processing power capacity of cloud providers, bandwidth capacity of cloud providers, storage cost of cloud providers, processing power cost of cloud providers, bandwidth cost of cloud providers are changed and the numerical results are described. The results show that the optimal solution is not changed and stayed at optimal.

TABLE III
NUMERICAL RESULTS FOR SENSITIVITY ANALYSIS

Decision Variables	Size of data buckets	Processing power of data buckets	Bandwidth of data buckets	Storage capacity of cloud providers	Processing power capacity of cloud providers	Bandwidth capacity of cloud providers	Storage cost of cloud providers	Processing power cost of cloud providers	Bandwidth cost of cloud providers
	$a_1 = 19.9$ $a_2 = 19.9$ $a_3 = 19.9$ $a_4 = 19.9$ $a_5 = 19.9$	$a_1 = 16$ $a_2 = 16$ $a_3 = 16$ $a_4 = 16$ $a_5 = 16$	$a_1 = 6.91$ $a_2 = 6.91$ $a_3 = 6.91$ $a_4 = 6.91$ $a_5 = 6.91$	$j_1 = 1005$ $j_2 = 2005$ $j_3 = 1005$ $j_4 = 505$	$j_1 = 1510$ $j_2 = 1210$ $j_3 = 3010$ $j_4 = 1510$	$j_1 = 377$ $j_2 = 502$ $j_3 = 627$ $j_4 = 252$	$j_1 = 0.75$ $j_2 = 0.85$ $j_3 = 0.75$ $j_4 = 0.65$	$j_1 = 0.55$ $j_2 = 0.45$ $j_3 = 0.65$ $j_4 = 0.55$	$j_1 = 0.30$ $j_2 = 0.35$ $j_3 = 0.40$ $j_4 = 0.25$
$X_{a_1 j_1}$	0	0	0	0	0	0	0	0	0
$X_{a_1 j_2}$	15	15	15	15	15	15	15	15	15
$X_{a_1 j_3}$	20	20	20	20	20	20	20	20	20
$X_{a_1 j_4}$	0	0	0	0	0	0	0	0	0
$X_{a_2 j_1}$	0	0	0	0	0	0	0	0	0
$X_{a_2 j_2}$	0	0	0	0	0	0	0	0	0
$X_{a_2 j_3}$	30	30	30	30	30	30	30	30	30
$X_{a_2 j_4}$	0	0	0	0	0	0	0	0	0
$X_{a_3 j_1}$	0	0	0	0	0	0	0	0	0
$X_{a_3 j_2}$	20	20	20	20	20	20	20	20	20
$X_{a_3 j_3}$	0	0	0	0	0	0	0	0	0
$X_{a_3 j_4}$	0	0	0	0	0	0	0	0	0
$X_{a_4 j_1}$	23	23	23	23	23	23	23	23	23
$X_{a_4 j_2}$	2	2	2	2	2	2	2	2	2
$X_{a_4 j_3}$	0	0	0	0	0	0	0	0	0
$X_{a_4 j_4}$	0	0	0	0	0	0	0	0	0
$X_{a_5 j_1}$	0	0	0	0	0	0	0	0	0
$X_{a_5 j_2}$	35	35	35	35	35	35	35	35	35
$X_{a_5 j_3}$	0	0	0	0	0	0	0	0	0
$X_{a_5 j_4}$	0	0	0	0	0	0	0	0	0

4. Comparison with ODT Algorithm and without ODT Algorithm

In this subsection, the experiment is performed by varying the number of data buckets from each aggregator from 5 to 25 and comparing the result using ODT algorithm and without using ODT algorithm based on the weights ($w_1 = 0.1$, $w_2 = 0.9$) as depicted in Fig. 3.

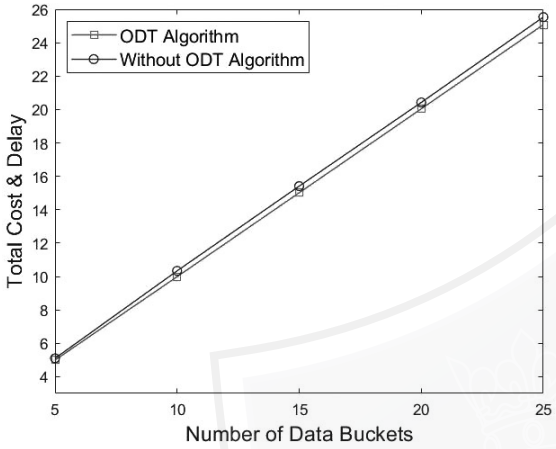


Fig. 3. Result comparison with ODT algorithm and without ODT algorithm.

As shown in Fig. 3, the result of using ODT algorithm is lower than that of without using ODT algorithm. Without using ODT algorithm, when the data buckets from aggregators are randomly transferred to cloud providers, it can incur to higher cost and latency. In contrast, since ODT algorithm applies multi-objective optimization, it is able to minimize total cost and delay for data allocation from aggregators to cloud providers.

VI. Conclusion

In this paper, we have proposed a system model of cloud-based meteorological sensor network in which aggregator approach is applied as an interface to alleviate bandwidth limitation for transmitting data from sensors to cloud. In proposed system model, optimization approach to capacity planning of aggregators is first presented. The result shows that using optimization approach can determine the optimal number of aggregators to meet the performance requirement for data from sensors while the investment is minimized. Moreover, Optimal Data Transmission (ODT) algorithm based on multi-objective optimization approach is also proposed to minimize cost and delay for data transmission between aggregators and cloud providers. Then, the proposed ODT algorithm has evaluated by numerical studies and experiments. According to the numerical results, ODT algorithm can optimally distribute the data buckets from aggregators among various cloud providers with the minimum cost and delay.

For the future work, we will consider the uncertainty of data arrival rate from sensor nodes and apply stochastic programming with two stages to minimize the total cost for capacity planning of aggregators.

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Gamification's effect in Social Media on CSR activities

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Received: February 15, 2019/ Revised: March 15, 2019 / Accepted: May 3, 2019

***Abstract*— Social Media Marketing is to create brand awareness to the target audience. Many Corporate Social Responsibility (CSR) is using social media with the aimed to distribute information widely and reach more participant. However there is some concerned with budget, participation and other factor that involve which might lead to not enough participant to keep the project on. In order to respond, a gamification method is use to develop the content and process to increase participation. The result shows that the content that developed and using gamification in the process has increase the participant more than triple of regular content. This fact shows that gamification can be applied into social media content and process which increase participation of CSR project.**

***Index Term*—Gamification, Corporate Social Responsibility, Social Media Marketing, Participation.**

I. Introduction

In the present, social media such as Facebook or Twitter has become a part of daily life. Different people have different intention of using the social media. Some of them use for entertaining while other might use for business. This has create a new business opportunity for e-Business online. More over Thailand economy are step up to Thailand 4.0 that change economy structure to value-based economy that is driven by innovation and technology. The concept of Thailand 4.0 is to do less but gain more through innovation and technology. One of the five field that government concerned and support is Digital Technology and Internet Industry which is Creative and High-Value Service Industry. Many people and organization that see the opportunity have use social media in marketing. Statistically the number of Facebook users have been growing since 2015 from 17.57 million to 21.94 million in 2018 and was predict that it will grow to 25.13 million in 2022 [1]. This growing number of users show a potential market that organization or company can target in marketing their service and products.

Even there are more than 20 million users of Facebook online and active however to develop content that suit the users included in the potential target group due to various reason such as no purpose behind the content, inability to deliver the message, lack of tactical digital marketing, etc. Sometime the content may get drowned by other online content. Due to that many businesses want to promote and get the target customer attention which might release the content nearly the same time. This make the content to be in the position that might not reach the customers at all. Moreover, online marketing content might not be interested to the users. Many website that sell the space for commercial have shown advertisement which sometime can make users feel inappropriate or annoying and result in closing the Ads immediately. As a result, the company not only have to develop the service and product to complete with competitor in the market but also have to make the content that would draw attention as well in order to deliver the message to the customer.

One of the selected Solution is to use Gamification Method in social media marketing. Gamification is to apply the gaming method to the activity which resulted in increased participation and also creating entertainment for the user. The purpose of this research is to study and apply Gamification Concept to Social Media Marketing. Its aim to help increase participation to the online content which can resulted in more customer to the business and also a guideline for Business Company to use in develop online content for social media market.

II. Literature Reviewl

Social Media Marketing can be describe as using social media network to create brand awareness and booting website traffic. To achieve such purpose the content needs to be unique in order to attract more attention [2]. The content can be created in various forms that suits the company and target customer. The advantage of using social media marketing are [3]:

• The content can reach a large number of people and can be accomplished free of charge.

• The traffic of the website can be increases through social and business networking which can increase page rank and search result.

• The social network can be integrate with paid advertising to increase the performance.

• The credibility can be increase and verify by others participating which can help increase trust.

• There can be social interaction and interactivity among users in the social network. This can help increase the awareness and participation in the site.

• The social media contains user profile which can help target and direct the content to specific users to increase effectiveness.

• There is also a drawback on social media marketing as well if not manage properly. The disadvantage of social media marketing include [4]:

• To develop content or manage the social media marketing can be time consuming. This is because the admin need to response on the comment or question from many users online.

• There can be trade mark and copy right issue due to the content online might be copy or duplicate easily. So competitor might duplicate the idea and implement it to be better than original.

• The trust issue still a main concerned in social media. Due to the content and users are online, sometime it is hard to trust the content that was create whether they are legit or not.

• Negative Feedback that might be given by various users in social media. The feedback can discredit the company whether the feedback content is true or not. The content in social media can spread very fast and reach many people.

Even company can gain more benefit through the use of social media marketing. However it is not easy to accomplish due to time consuming and issue that might occurred with the content. The content might be copied and duplicated or might face copyright issues. Many people still might feel that the content might be a junk content due to trust and feeling. Moreover, competitor might give negative feedback which affect the company's reputation.

The content in Social Media also plays an important role and becomes leading marketing technique [5]. The content developed by using the consumers' point of view to build relationships by engaging content. Several research states that the content in social media becomes acceptable to users more than an advertisement [6][7]. This might be result from the content was generated by common people similar to user so they feel like realistic more than content from the company that might be farfetched. As a result, the new strategy for company to create the content in social media is focusing on identifying what type of content will be interesting to the relevance group of target audiences [8]. In order to accomplish that the company needs to study the target group on what kind of content (i.e. photo, graphic, or video) is suitable to the group. However, even through the study and developing the content, it might still not interactive or engaging audiences as it should be. The company will face a problem that invest on the research to study the target audience and spend money on develop the content but the content might not reach enough audiences as it should be. So a method to get audiences to interact and engage with the content is still needed to increase the content interest.

Gamification is a method that applied gaming concept to the process or activity to motivate the participant in order to increase participation or engagement [9]. The gamification can be applied in various ways which converts regular activity into a game that participant can enjoy such as applied to education to create game based learning [10]. The concept of gamification are:

• Game Mechanics: Applied the game mechanic to activity such as point, leader board, prize, reward, etc. These will stimulate participant thus increasing engagement and involvement among the participants. The prize system will get participants attention. The participant will engage with the activity in order to get achievement. The achievement from game mechanic is not only for single participant completion only but can also be achieve through competing with others.

• Experience Design: Designed the activity into a game including the story, how to play, space required, format of the game so the participant can experience and feel like playing a game. If the activity is well design this will make the participant feel like he is a part of the activity thus will increase engagement of the participants.

• Digital Engage: Develop participant attachment with the device during the process or activity in order to complete the goal. The time requirement for game completion is vary. Some of activity might take less time for completion while other might take longer. In case of the long activity, the device or tool that required might be an issue due to participant will have to get familiar with it which can take time to learn. So it should not be complicated or otherwise participant might feel it is hard and will be uncomfortable through the rest of the activity.

• Motivate People: Through the game mechanic participant will be motivate to complete the activity or task. The participant will be motivate to come up

with the new idea or innovation in order to complete the task.

• Goals Achievement: the game mechanic can guide or support participants to complete the goal. Some part of the task or activity might be complicate or confusing which might give the participant hard time to complete it. The game mechanic need to have the support of help system that can guide the participant to task completion.

• Gamification can be applied in various way to create the task or activity that is more engaging. Such method can be applied to develop the content that can draw audience's attention and willing to follow and result in increases participation in social media marketing.

III. Methodology

The content for social media marketing will be develop based on Gamification concept to make the content more interesting with the aim is to increase participation of audience with the content. The component of Gamification that used to applied in developing the content are:

• Game Mechanics: Applied the prize system to social media marketing. The content will be developed in a series with 3 chapter and will range around 2 to 2.5 minutes. Each episode of the content the audience will gain medal when complete the activity. Also the audience will earn the point in each episode to get the reward. The reason that use both medal and point for game mechanic is that the audience will gain immediate reward to point system which will make audience realized that they can gain something after the participation. The medal system plus point system will gain the bigger prize reward. This is to increase and keep the audience in participation. With the social media that people can like and share, the number of participation can also be increases.

• Experience Design: The content is designed in the story which divided into 3 episode to make the content enticing to follow. The content will explained how to participate so the audience will received all the necessary information from one source and also make the participant feel like he is a part of the activity and result in increase engagement. The flow of game mechanism is present in Fig. 1.

• Digital Engage: the digital engage is one of the crucial part because it is how to get the audience retention. It is to make the audience attached to the content and platform. From various research the content of the online add should range between 2.50-3 minutes any longer than that will lost the audience attention. Such the concept will be applied in the content of social media marketing as well. So the total time for audience involvement will be 3 minutes or a little more than that. Thus the process of involvement and to get the point or medal will make it not to complicate which the audience and complete the task by themselves.

• Motivate People: the content and process will develop to motivate audience to complete the task. The game mechanism that will be used on the social media is the activities of like, share, comment, and so forth. These action will be calculate and provide code which can be used to gain reward.

• Goals Achievement: the help mechanic will be provide in the research to help participant complete the goal which will be provided through help system. The online game system will be develop to support social media marketing which developed in the form of web based. The content that the audience view and complete the task in social media will earn them a point which will be trade into code to use with the online game.

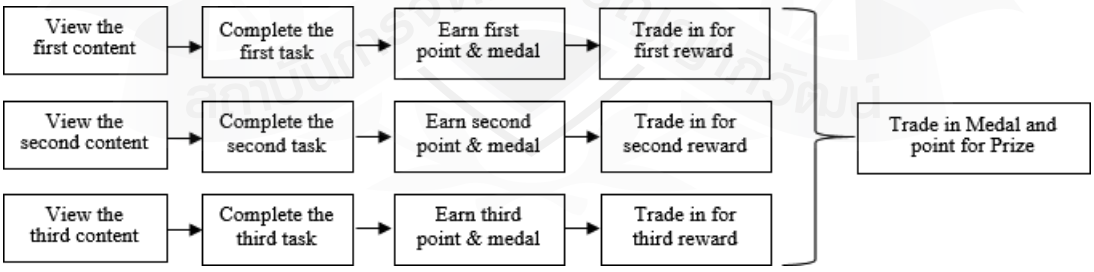


Fig. 1. Game prize and reward mechanism.

After audience received the content in social media marketing they will have a series of tasks to complete in order to receive the point. The game prize mechanic develop in flexible way which participant can earn some point even they are unable to complete the task. However for those that complete all of the task will earn more point plus medal which can be trade in for reward and Prize. Once the task completed, participant can submit information to the system to verify. After the verification from the system the code will be generate and send to the participant to use in the game system.

IV. Experiment: A Case Study Of Social Media Marketing For Csr Project

The concept of Corporate Social Responsibility (CSR) is for the companies or organizations to act or contribute back to a society and environment. The problem that arise is that most of the time such news of CSR event spread on social media very quick and wide. However once it has been sharing sometime people forget about event and not participating such event. So many time that the event has many like and share but not many participating. So gamification have been adopted to develop the content to promote CSR on social media. In this research the content for CSR project developed into two types: the first one is just a regular ads that provide information of the project and the second one is the ads that develop by using gamification mechanism. Both of ads will be present to 10th grade high school student in different school that has the same CSR project and similar environment and test subject. The aims of the experiment is to study whether content that develop with gamification and using game mechanic can increase participation in social media marketing.

The target group of this research is 10th grade high school student one class (around 50 students) from each high school. The process is to presents the content of CSR project in the class though Facebook then see how the student react and participated.

TABLE I
Target group population

Name	Boy	Girl
High school A	24	18
High school B	20	24

The content for CSR project is to reduce the use of plastic bag in a VDO format. The content will be post and distributed on social network, in this study will be on Facebook. The ads content will be 1) Impact of plastic bag to environment 2) Reduce & Reuse the plastic bag 3) Garbage bank; turn plastic bag into profit. These content will be developed into ways: regular content that provide information and content that adapted gamification. Both content will concluded with like and share sentence for student to share the content with other to see how participant can be increase in CSR project that might not benefit them but benefit the community.

The VDO content will be release on the Facebook every 10 days. This is to give participants sometime to complete the task. Once the participants viewed the content and complete the task. They can submit the information to the system then the game system generates the code based on the level of completion for participant to use the code in the game to upgrade the character to complete the game.

The game system used information that participant submitted and generate code for participant to use in the game to develop character which they can complete with other online though the game system. There are two part of the information that requires; the first one is questionnaire about the content which randomly selected and the second one is the information that participant complete the task with. The game mechanic included the social network feature which participants can shares the game progress and result online to increase engagement and competition.

V. Evaluation

The evaluation of the research on increase participation through gamification was collect by questionnaire online through the game system and also through the data that collect on the social network. The questionnaire distributed to both target groups to collect the data for comparison. The questionnaire cover how the participant feel about the content, the engagement of the content, the participation toward the content, and so forth. The summary result for evaluation is in the table below.

TABLE I
Evaluation result from high school a (regular content)

Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1) The content is motivate and make you want to engage in CSR project	0.00	4.76	80.95	14.29	0.00
2) The Flow and process is easy to learn	0.00	9.52	76.19	14.29	0.00
3) The content is engaging which you would like to continue playing	0.00	7.14	47.62	45.24	0.00
4) You feel like you are part of the content	0.00	0.00	47.62	52.38	0.00
5) The content make you want to share the content	0.00	0.00	35.71	64.29	0.00
6) Number of participant at the beginning					42
7) Number of share content					61
8) Number of like content					158
9) Number of participant at the end					69

TABLE II
EVALUATION RESULT FROM HIGH SCHOOL B (CONTENT WITH GAMIFICATION)

Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1) The content is motivate and make you want to engage in CSR project	0.00	50.00	38.64	11.36	0.00
2) The Flow and process is easy to learn	27.27	40.91	22.73	9.09	0.00
3) The game system is engaging which you would like to continue playing	43.18	45.45	11.36	0.00	0.00
4) You feel like you are part of the content and game	25.00	45.45	27.27	2.27	0.00
5) The prize/ reward system is motivate for completing the task	47.73	43.18	9.09	0.00	0.00
6) The content and game system make you want to share the content	59.09	31.82	9.09	0.00	0.00
7) Number of participant at the beginning					44
8) Number of share content					148
9) Number of like content					237
10) Number of participant at the end					141

From the evaluation result and collected data it can be clearly seen that use of gamification (in High schoolB) can increase the engagement and participants. The engagement is increase through like and share which result in number of participants at the end of CSR project increase more than triple through gamification. As for result from questionnaire, the result is in the range of agree to strongly agree with gamification.

The content developed with gamification concept result in 50% of participants found that it is motivate and want to engage in CSR project while only 4.79% only found motivate and want to engage in regular content. This is because the content develop with gamification create the story that give participant and experience that they are part of it and the game system make the content very interesting. Participants want to participate and learn what they will get as prize or reward.

The game system is also major contribution in which make the participant want to participate and continue with CSR project. From the result it can be seen that just content alone participant feel more on the neutral range with CSR project. This is because participant feel like it is a one way communication which no interaction between participant and content at all. However with gamification participants feel like it is more interactive the content was develop and link to the game which make participant eager what to learn, what are the mission and what prize will they get.

By involving social network feature such as like and share to the game system help increase the participants. From the data collected from gamification method, at the beginning when the first VDO is release 38 high school student like and share the content within an hour. After 24 hours, there are 79 likes and 63 shares of the content. By the end period of the first campaign, there are 132 likes and 99 shares. The number of participant is increasing in each content and game campaign and finally at the end of third campaign there are 237 likes and 148 shares of the content. The period of the campaign show no significant change to the result. The number of participant did not increase in the campaign with longer period of time. Participant trend to prefer a shorter campaign because they can get reward faster.

VI. CONCLUSION

From research study gamification can help increase engagement and participation through the use of game mechanic. In the field of CSR project, this is needed because some CSR project does not have budget to cover the event and will be operate mainly on participation. This can be applied in the social network where content will be generate and distributed widely. Thus making the content more interesting and become two ways communication which participant can feel like he is a part of it and become engaging through the game design mechanic. The result of the study from both high school target groups, it shows that the target group that use gamification is more lively and more activity that occurred during the content and campaign. This can be worthwhile when develop the content on social network because there is a cost in developing the content such as money, time, manpower, etc. So if there is not enough view, like, or share, then the content might not reach enough audience and might not worth when compare to the development cost. Gamification has proven to be quite useful mechanic to apply in various activities that aimed to get more engagement and participation.

VII. Future Work

This research study focused mainly on the develop content with the game mechanic and pay little attention to develop the game system. The improve version of the game system is needed inorder to help participant feel the game experience. The game system will make the event more interesting and more engaging. Participants will gain better experience though well design game mechanic. A well design game mechanic can generate an in game reward which can reduce the cost of prize and reward. Other works that can be add on is to make the system become more general which can be used in various CSR project for more engagement and participation to make the project sustain. Lastly the study of gaming and Social network's relation is also considering for future work.

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JMM Gimbal Stabilizer

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Received: February 15, 2019/ Revised: March 15, 2019 / Accepted: May 3, 2019

***Abstract*—To develop and improve the traditional gimbal stabilizer for smartphone or camera-based acquisition device, the handle part is the main point to be considered. Product Design and Development (PDD), Ergonomic Design, and Rapid Prototyping (RP) have been applied for creating the guideline of the conceptual model of this developed gimbal stabilizer. Dimensions and physical characteristics of the gimbal's handle have been created by applying the concept of ergonomics to fit the people who use it. Using this proposed design can help the users to minimize fatigue during prolonged imaging activities.**

***Index Terms*—Ergonomic Design, Gimbal Stabilizer, Imaging Acquisition, Product Design and Development (PDD), Rapid Prototyping (RP).**

I. Introduction

Smartphone has become technology and it is counted as one of the big influencers to change the way of life of the people currently. People are able to share stories via social media instantaneously by using smartphone camera. Blur and shaky of footage can happen when smartphone users are doing some activities. A support equipment such as camera stabilizer was invented for professional photographer to use in motion picture industry. For amateur and person who interested in taking photograph and video by using smartphone, gimbal stabilizer is a device which can reduce smartphone vibration and movement.

Smartphone users can connect to social media platforms and share their stories, findings and experiences at anywhere and anytime. According to Thailand National Statistical Organization, around 89.6 percent of people in Thailand has a mobile phone (approximately 56.7 million person) Social networks such as Facebook, Line, Twitter, Instagram are the top activities that smartphone users spend time on their smartphones [1].

Nowadays, people using smartphone to take pictures or short video clip instead of using a full-size video camera because smartphone is small and light enough to be carried or moved easily. But there are some problems that might happen when the people are taking videos by using the smartphone [2].

These have led to our research to develop and improve the gimbal stabilizer for smartphone where the *handle part* is the key part to be considered. The new design of handle shape might reduce the fatigue and the failure occurred during imaging activity. Curvature surface of hands and postures performed during taking photos will be taken into account by applying the concept of ergonomic design. Some direct messages obtained from the interviews and questionnaires help the researcher to understand about the hidden needs and requirements of the user on the commercial gimbal stabilizer. The users feel uncomfortable while they are using the equipment for a long time.

II. Related Works

In order to create and develop the new design of gimbal stabilizer, three main considerations are mentioned and analyzed in this section.

A. Camera Stabilizer

Steadicam is one of the camera stabilizer items used to isolate the camera from any movement made by the user. It is a well-known device to keep camera stable and can take high quality footage while the user is moving. The steadicam appears to be very effective at isolating movements. However, the steadicam may not be the best choice to use for casual video taking because of the weight and size of the device. [3] The picture of steadicam is shown in Fig.1.



Fig. 1. Steadicam [4].

Three axis roll-pitch-yaw has been presented in an advance gimbal-camera stabilizer. This skeleton is attached to a platform. Each of axis is independently driven by motors with encoder feedback.This gives angular position and velocity feedback. The device creates natural movements of the arm and counteracts any unwanted movements to make creating seamless motion of video footage. Panning operations can be done by using joystick, and the phone can be instantly positioned by hand [5]. The advance gimbal is shown in Fig. 2. However, guiding slots at the handle provide the difficulties to the user's hand. Since, for operating task with one hand, the user might not perform well to align the fingers one each particular slot. Straight handles are suitable for the actions or activities that the force is applied perpendicular to the straightened forearm and wrist; the force is applied vertically. The user might feel some stresses distributed ranging from the palm though the shoulder. The weight of the device or handle is one of the main issues that need to be concerned during the product design stage.



Fig. 2. Advance gimbal [6].

B. A Check-List for handle design and the effects of tool handle shape on hand performance, usability and discomfort

• The troubles with handle

The main reason for creating the new items is to enhance the capability of the humans to easily communicate with machines. Designers or the experienced people, in general, design the specific characteristics of the handle. Recently, most of handles are too small, too stiff, and they contain sharp edges or awkwardly placed that make the user feel uncomfortable. Applying their hands or fingers to grab, control or hold for a long time cause the pain around forearm and palm of the hand. Most of contact between hand and equipment are inaccurate and unsafe which can cause injuries to the user. Bulky items like refrigerators and heavy office equipment still have to be moved and contacted by using human hand [7]. The appropriate design is very important for preventing upper-extremity musculoskeletal disorders (e.g., carpal tunnel syndrome, hand-arm vibration syndrome or tendonitis) [8-9]. In order to determine the optimal diameters for maximizing finger-force exertion, comfort, contact area; Harih and Dolsak (2013) have developed ananatomically accurate static digital human-hand model (DHHM) [9]. Applying this method, therefore, the chances of cumulative trauma disorders (CTD) could be minimzed. The handle with higher contact area and anatomical shape of the handle, extensive deformation of the soft tissue can be avoided; preventing excessive load on the hand. The obtained design; anatomically-shaped tool-handles based on the developed DHHM with optimal power-grasp posture, can increase the contact area and the subjective comfort-rating, thus increasing user performance and lowering the risk of CTD.

• Power grip

Since the human body is capable of a wide variety of positions, there are many researches that mention about the design of physical parts containing some extra curvature surfaces, features or shapes to support the human body parts, especially, sensory organs; eyes, ears, nose, tongue, and skin. The design of handle is one of the popular topics which are quite challenge to create the platform or pattern for fitting the area of interest. The position of fingers need to be bunched tightly around an object and overlapped by the thumb [10]. Illustrated in Fig. 3 is the position of the thumb and fingers on the handle. The appropriate handle with enough thickness can help to separated fingertips from the palm.

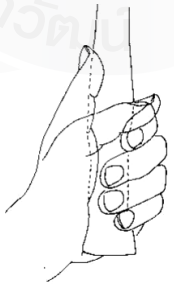


Fig. 3. Power grip–thumb can be straightened as a precision component [11].

Moreover, the large area of contact is very important criteria for preventing strength of the grip. The spots of local high pressure are not recommended to prevent strength of grip that makes the user feels uncomfortable. The basic pattern and the design of the power grip are relied on the alignment between the thumb and a

handle where the thumb should be straight along the back of a handle.

• *Size and Shape*

For the size of the handle, length should be around 10 to 15 centimetres in order to fit with the palm, longer length for large-handed population, shorter length if the butt end of the handle is to fit into the palm, when it should be rounded. Thickness should be 3 to 4 cm in diameter, to allow the thumb to just cover the end of the index and middle fingers. The shape of the grip or handle can be varied according to the size and length of the device. Normally, cylindrical shape of the polymer material is used as the grip for twisting round the handle (e.g., a one-piece rolling pin). If the rolling pin has an axle inside it, the handle will give a more secure grip. Uniform diameter and smooth surface along the length can make the user hand slide along the handle (e.g., an axe handle).

Thickened at the center to make secure grip and prevent sliding; it is seen in a sheep-shearing hand-piece. This is not shifted within the palm, but there is much wrist and arm movement. Some environmental conditions (e.g., oil, sweat or dust) have direct effect on the way to maintain the grip in place with high secure level. Flattening for the thumb and fingers, to prevent unwanted twisting (e.g., a saucepan handle). No sharp edges or high spots in the area of grip. These can decrease comfort and security of the grip and they may cause injury to the user. The raised area or an edge along the handle length is quite interesting and useful on the end of the non-grip area of the handle, to act as a guide to save the position of the hand, and as a warning sign.

C. Examples of the popular tool handles available in the market.

Presented in Table I are the comparisons of image assistance devices which are *selfie stick*, *tripod*, *Steadicam*, and *handheld gimbal*. Remote control indicated that user can take picture or video remotely without touching the smartphone screen. The specific characteristics of these devices were compared where "*the stabilize mechanism*" was the key consideration. The handles were designed to provide different p atterns of grip; therefore they could be suited to the hand tool interaction in particular hand areas [12].

The hand grip exertion and ability to use the handgrip were negatively correlated with personal assessment of hand and finger discomfort, so that a lower level of hand and finger discomfort corresponded to higher hand grip exertion and usability. These results provide a better insight into the performance and usability issues when using hand tools which can be utilized by tool manufacturers in order to improve industrial hand tool design. Ergonomically designed hand tools can reduce the fatigue of the user, mechanical illustration, the chance of developing an injury and risk factors for musculoskeletal symptoms. In addition, to improve the quality and performance of hand tools, it is possible to improve an efficiency and work productivity. The design of tool handle which interfaces with the human hand is a major importance thing. The shape of the handle should be designed to get the best performance, usability and contact area between the hand and the handle part to provide better pressure distribution and reduce the shape edge in order to decrease the contact stress that will occur with hand, leading to reduced discomfort.

TABLE I
IMAGE ASSISTANT DEVICES-COMPARISONS

Product	Functions
 Selfie stick [13]	• Remote control : Yes • Battery : N/A • Stabilize mechanism : N/A • Tripod : N/A
 Tripod [14]	• Remote control : No • Battery : N/A • Stabilize mechanism : N/A • Tripod : Yes
 Steadicam [15]	• Remote control : No • Battery : N/A • Stabilize mechanism : Yes (Analog) • Tripod : N/A
 Handheld gimbal [16]	• Remote control : Yes (Built-in) • Battery : Yes • Stabilize mechanism : Yes (Motor) • Tripod : Optional *Remote control indicated that the user can take picture or video without touching the smartphone screen.

III. RESEARCH BACKGROUND

Presented in this section are the background of the research for identifying the user's behaviors and perceptions in smartphone and supported devices. These people will be accounted as the target group of the new gimbal stabilizer design. Two phases of Product Design and Development (PDD) have been described in the following subsection.

A. Phase 1: Customer's behaviors on smartphone

After collecting some ideas about customer's behaviors on smartphone, to create the drafted design of the new gimbal stabilizer, three main activities were established; *data collection process*, *data analysis*, *discussion results and conclusion.*

1. Data collection

In order to create gimbal stabilizer for smartphone, market survey has been conducted by using questionnaire. Questions have been made to determine importance parameters such as average smartphone usage time for a day, popular activity on smartphone, opinions about design of gimbal stabilizer, and the most important question which is price of gimbal stabilizer that users are willing to pay for this equipment.

2. Data analysis

There are 3,238 participants answered in this questionnaire. Results from the questionnaire indicated that around 92.7% of participant has age between 13 and 26 years old. 85.5% of participants are high school student and university student. Around 42.3% of participants used their smartphone to take pictures or videos every day. 96.6% has faced the problem with image or footage blurring when smartphone users try to take the pictures and videos. More than 80% has never used the gimbal stabilizer and about 93.9 % of the people are willing to use the gimbal stabilizer if this equipment can improve quality of videos. The results obtained from the questionnaire indicated that the most popular design of gimbal stabilizer is one handheld design which is traditional design of gimbals that are available in the market. 3,000 baht is the price that most of questionnaire participants are willing to pay for this equipment.

3. Discussion of questionnaire results and conclusion

After our group obtained findings from questionnaire, there are some concerns about cost of make a functional prototype. Since the creation of prototype is not a mass production, so the cost of creating functional prototype might be more than 3,000 baht. One handheld is popular design of gimbals in the market, but most of handles are cylindrical shape with no curvatures that support user's palm of the hand. Handle part is only component that touches with the user's hand. The researchers have tried to improve the design of the handle part to make sure that it fit perfectly with user's hand.

B. Phase 2: Translating requirements to be design

In order to translate the requirements of the target customers to be the gimbal design, factors affecting gimbal stabilizer functions are considered and classified into three groups; *weight of smartphone*, *weight of gimbal stabilizer*, and *size of smartphone*.

• *Weight of smartphone*

The phone that is inserted into the gripper has different size and weight which can be affected with the stabilize control system of the gimbal. The more weight of the phone, the more force of the motor that have to apply to the stabilize control system.

• *Weight of gimbal stabilizer*

The first thing that the customer will decide to buy the product is how heavy of the product is. The weight of the product is related directly to the time that how long the customer can hold the gimbal stabilizer.

• *Size of smartphone*

The size of the phone is related directly to the balance of the stabilizer control system of the gimbal stabilizer. The gimbal stabilizer has to calibrate itself every time when the operator turns on the switch. The system will find the balance of the stabilize system by using the weight, size, and position of the phone that is inserted into the gripper. In order to create the new design of gimbal stabilizer, research background about product design and development, and ergonomic design have been studied and analyzed.

IV. JMM Gimbal Stabilizer

After translating the customer's behaviors and requirements from the self-administered questionnaires, the drafted design was constructed. The key theme of this developed design was raised by using the concept of "*it's just me, myself and I*" where the users can activate and generate clean and clear images and video clips without blurs and distortions affected from the external issues by themselves. This one was quite similar to the function of "*selfie stick device*". This new alternative direction that can assist the digital-life application, "*Just Me, Myself and I*" (*JMM*) gimbal stabilizer has been established and developed in this research. The components of smartphone stabilizer were smartphone grabber, handle part and structure of the gimbal stabilizer.

A. Expected design from the questionnaires and direct interviews: "Handle Part"

The design of gimbal stabilizer and prototypes are decided to be spline-structure characteristic where the design that most of the people prefer to use is one hand operate design with the built-in remote control and joy stick in the handle part. The design of the gimbal stabilizer is concerned about the compact size. The key concepts for this new model are focused on *portable size*, *foldable*, and *easy to use*. The handle part is universal design which has round shape

without any sharp edges. The diameter of the upper and lower part of the handle will be larger than the middle part which can prevent from falling. There will be a hand strap for slipping on which perfectly fit with the user's hand. The drafted idea of the proposed approach of gimbal stabilizer model is shown in Fig. 4.

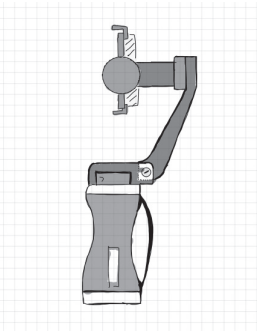


Fig. 4. Conceptual model of Gimbal stabilizer.

B. Concept of "3F's approach" for handle part

The research of interest in this developed JMM gimbal stabilizer is the "handle part"; therefore, the emphasized directions of handle characteristics and specific details such as shape, dimension, and weight will be presented and mentioned in the design phase (Table II). JMM gimbal stabilizer embodies the following themes:

1. Form

Size and dimension of the handle part of gimbal stabilizer should be equal to 15 cm in height and 4 cm in diameter, respectively. The design of handle part will be shaped and constructed by applying the ergonomic design. The landmarks for the anthropometric data are shown in Fig. 5 to 7. Landmarks are points on the hand between which measurements were taken between on the right hand of all subjects.

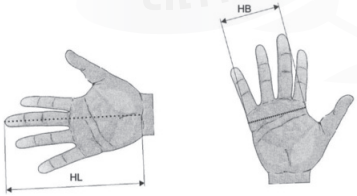


Fig. 5. Landmarks for hand length and hand breadth.

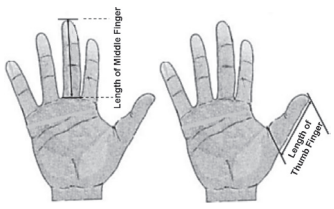


Fig.6. Landmarks for measurement of middle finger and thumb finger length.

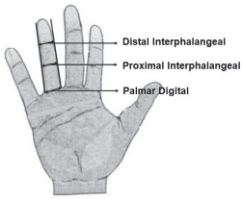


Fig.7. Landmarks for measurement of breadth of fingers [17].

TABLE II
TOOL HANDLE DESIGN FOR POWER GRIP

Anthropometric data variables	Definition
Hand length	Defined by measuring between the wrists until the longest fingertip on the hand, usually be the middle finger and wrists
Hand breadth	Defined by measuring the length of palm perpendicular to hand length
Length of thumb finger	Defined by measuring between the palmar digital until the tip of thumb
Length of middle finger	Defined by measuring between the palmar digital until the tip of middle finger
Grip diameter	Defined by measuring the largest cylinder can be held within the condition that thumb and the tip of middle finger must be in contact
Diameter of distal interphalangeal (All fingers)	The diameter of finger at the distal interphalangeal joint
Diameter of proximal interphalangeal (All fingers)	The diameter of finger at the proximal interphalangeal joint
Diameter of palmar digital phalanx (All fingers)	The diameter of finger at the palmar digital joint

On the gimbal stabilizer handle part, there are no edges around holding area which can prevent from creating a mechanical irritation, obstructing blood flow and increasing a chance of developing an injury. According to *Kent Hatcher, Director of Consulting and Ergonomics Engineer for humantech.* [18] The drafted 3D virtual model of JMM gimbal stabilizer is shown in Fig. 8 and 9.

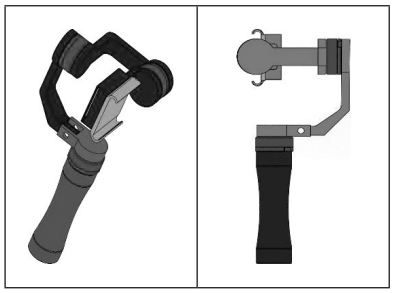


Fig. 8. The expected design of Gimbal stabilizer.

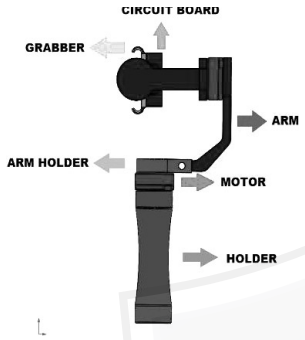


Fig. 9. 3D spline model with components.

2. Fit

The gimbal stabilizer consists of three main parts which are *handle*, *smartphone grabber*, and *stabilizer mechanism*. The dimensions and the details of the main components are explained in Table III.

• *Gimbal Handle*

Handle is the main point of contact between the user and the device This is where user hand movements are translated into smooth camera panning and tilt motions.

The shape and dimension of the handle was defined by the land mark reference of the palmar grip diameter. The middle part of the handle was designed to be smaller than the ends to prevent slippage of the hand along the handle axis.

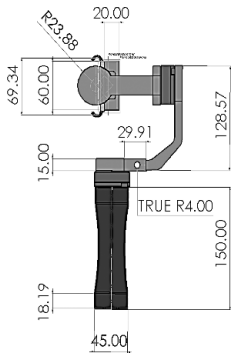
• *Smartphone grabber*

Adjustable grip which can hold different size of smartphone.

• *Stabilizer mechanism*

Stabilizer mechanism for controlling and stabilizing the smartphone consists of *three brushless motors* for 3-axis and *a control board*.

TABLE III
COMPONENTS OF SMARTPHONE STABILIZER

No.	Components	Picture
1	Smartphone grabber – The outer and inner length of the grabber are 69.34 mm and 60.00 mm, respectively.	
2	Handle part – The diameter and length of the handle part are 45 mm and 150 mm, respectively.	
3	Structure – The total height of the structure is 128.57 mm.	

3. Function

The function of gimbal stabilizer is to stabilize the smartphone by using the main components which are *control board* and *three motors* (brushless motor) as shown in Fig. 10. A tripod or a hand strap will be applied as an optional feature of this gimbal stabilizer.



Control board [19] Gimbal motor (T-Motor) [20]

Fig. 10. The main components for functioning stabilizer.

C. System-level design and detailed design

In order to identify the physical characteristics of the JMM gimbal stabilizer, all components were classified and expressed about their specific requirement, and operational/general stage conditions. These data can help the designer to minimize some mistakes that might be occurred during the design stage. Illustrated in Fig. 11. is the main frame of the developed design.

For stabilizer mechanism, four items are required: *motors*, *control board*, *battery*, *and input device*. All these items are the heart balancing movement and condition. However, time spent for checking and controlling these items is quite long, and they will be added to the prototype later after finishing entire designed part.

For handle and frame grabber, two modules will be considered and presented firstly in this research since the main concerns among image assistant components when the user uses the gimbal stabilizer device are well-fit handle, and camera grabber.

The price condition is the main issue that has direct effect on purchasing decision; therefore, the proper items will be mentioned and applied by doing some researches, especially, the handle part.

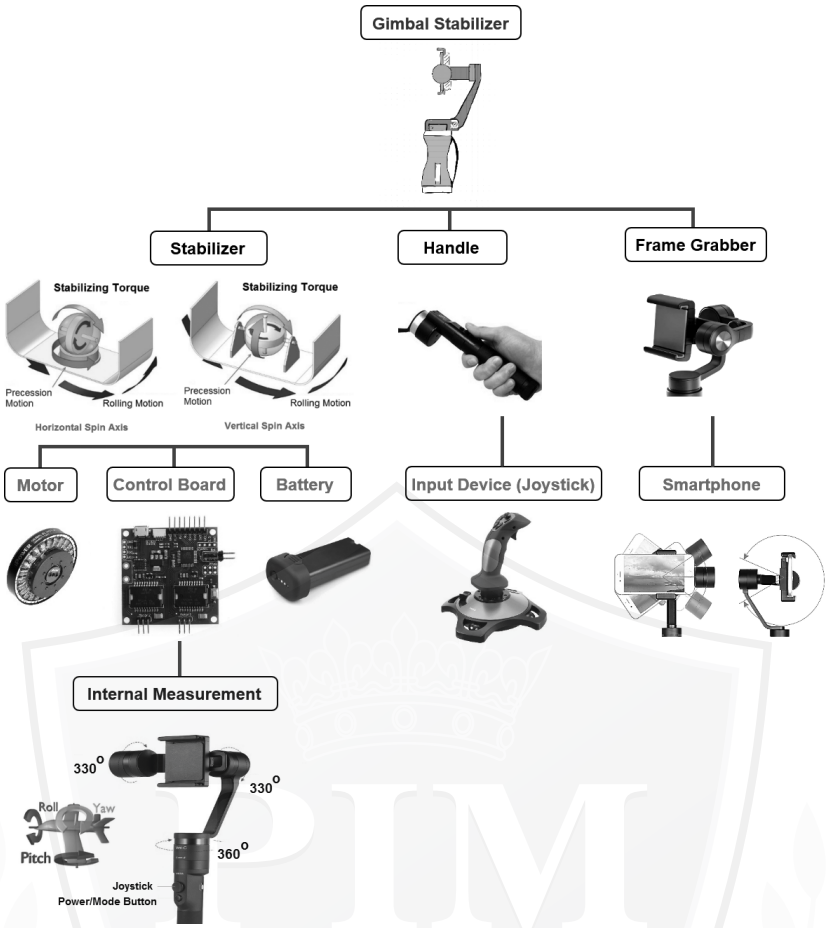


Fig. 11. The main frame of JMM gimbal stabilizer.

D. Extra considerations

From the main frame diagram, the *stabilizer* module contains and requires more details when compared to *handle* and *grabber* modules, since it is the most important function that support the whole system to keep high-stability during data acquisition. With insufficient motor, board or battery, the gimbal tries to balance the phone but goes into failure to function properly; it can adversely affect the stability of the product. To obtain compact-comfort style for this developed equipment, three items taken into account and explained as;

• *Brushless motor*

Brushless motors offer several advantages including high torque to weight ratio, high efficiency, increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling.

• *Control board–Inertial Measurement Unit (IMU)*

Inertial measurement units are responsible for sending camera acceleration and positioning data to the gimbals controller. IMU sensors for gimbals have a built-in gyrometer that required calibration before the equipment can operate. These sensors are sensitive to temperature change and the sensor required re-calibration overtime so the gimbal maintains good stabilization performance.

• *Gimbal Batteries*

Gimbal is powered by rechargeable Lithium Polymer (Li-po) or Lithium-Ion (Li-ion) batteries [21].

E. Prototype and refinement

In order to identify the proper design of the handle, six different designs (Fig.12) were created and used as the guidelines for demonstrating the proposed approach where the size, comfort and geometric shape were the key components and evaluated by 31 participants, 10% of them are the experienced people in the optical/image processing applications. The average time spent for holding each sample was 2 min. The factors were rated with the scores from 1 to 10. The results were shown in Table IV. The score of 1 means that the participant is not satisfied with the design whereas 10 presents high satisfaction level of the design.



Fig. 12. Six designs of the gimbal's handle.

TABLE IV
SATISFACTION SCORES OF SIX TYPES OF GIMBAL'S HANDLE

No.	Prototype	Model Details	Factors (avg. score from 1-10)		
			Comfort	Size	Design
1		**Top:** Taper down **Body:** Straight and small concave area connecting to the bottom section **Bottom:** Oval with one side flat **Extra:** Motorbike Grip	7.290	7.387	7.387
2		**Top:** Step with spline curve **Body:** Middle crater/ Convex **Bottom:** Concave up slopes increasing from the base point	8.129	8.000	7.000
3		**Top:** Thin prism with chamfer on one side **Body:** Spline and concave **Bottom:** Long prism	6.806	7.258	7.419
4		**Top/Body/Bottom:** Spline with finger groove **Extra:** Hollow shape	6.129	7.032	6.968
5		**Top:** Thick prism with chamfer on one side **Body:** Spline and concave **Bottom:** Long and thick prism **Extra:** Popular in the market	5.935	6.000	7.129
6		**Top:** Short cylinder and taper down **Body:** straight and Small concave **Bottom:** Concave and short cylinder	8.548	8.032	7.452

The model No. 6 presented the maximum satisfaction level for all the 3 factors; this design was chosen for making the prototype. The design of model No.6 was shown some special details about the comfort grip and fit with the user hand where the two mirrored sides (left and right) are exactly the same. Shape of the top left quadrant was the same as the bottom left quadrant, and the curvature surface of the top right quadrant was the same as the bottom right quadrant.

After 3D spline model has been made by using SolidWorks, Rapid prototyping (RP) method has been used to create a prototype by using 3D printer. The XYZ da vinci 1.0A 3D printer operated by using fused filament fabrication (FFF) technique. The material used is ABS plastic, which gives high strength and durability. ABS filament is used as printing material, filament has been heated to temperature around 240 ^{o}C which make the print material become molten plastic that can be formed into different layer of the workpiece. The 3D printing is classified as one of additive manufacturing where the product has been built layer by layer to form a geometry shape. The suggested material for manufacturing process. The prototype of this design is shown in Fig.13.

- *Handle part*: Polypropylene coated with rubber
- *Stucture and smartphone grabber*: Polypropylene
- *Stabilizer mechanism*: Polypropylene

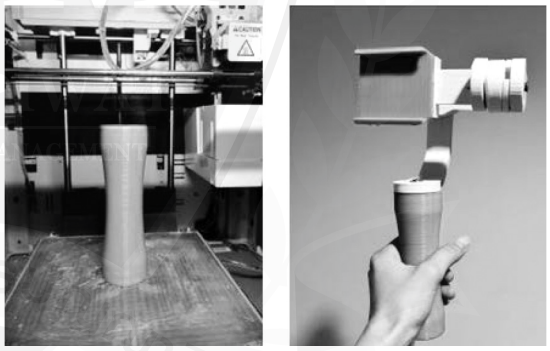


Fig. 13. 3D printed handle part (Left) and Prototype of JMM g imbal stabilizer (Right).

V. DISCUSSION AND CONCLUSION

Blur and shaky video footage can happen when the person who takes the video are walking or doing some activities. The gimbal stabilizer is an equipment which can solve this problem. User can use handheld device while shooting video without causing camera vibration or shake. Powered by three brushless motors, the gimbals have the ability to keep camera level on all axes as operator moves smartphone. Self-administered questionnaires were used for collecting data in order to obtain the customer's requirements. The 3D spline model is created based on concept of ergonomic.

The main problem of the traditional design was shown through *handle part* that makes the user feels fatigue because of the finger groove with silicone anti-slip handle. When the user holds the handle for a long time, the moisture (i.e., sweat) around the palm and finger areas makes the user feel discomfort or uncomfortable fit. These had let to our research to create an alternative design to provide compact-comfort way for the user to carry with less fatigue and this new model will afford the best feeling of the user's hand with two mirrored-side structure. The proper curvature surface (spline contour) proposed in this research can support all hand sizes without slipping during grabbing the handle.

After 3D spline model of the gimbal stabilizer is created, 3D printer has been used to create the first prototype. All components of gimbal stabilizer were printed out using 3D-printing RP process where the ABS plastic was the main raw material. Since each component was printed out separately, the assembly process was required and performed to get the complete prototype.

This research aims to present the new direction of the physical characteristic and design of the handle that will be evaluated and identified that, whether or not, the handle part can fit perfectly with user's hand. This first prototype will be applied for the next step to add the stabilizing mechanism to move as the real function.

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Optimal inventory control policy of a hybrid manufacturing-remanufacturing system using a possibilistic linear programming approach

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Received: September 24, 2018/ Revised: October 28, 2018/ Accepted: December 7, 2018

***Abstract*—Remanufacturing is the process of converting used products back to like-new products. Production planning of inventory control policies in the remanufacturing of used products with different prioritizations (remanufacturing vs manufacturing) is investigated in this case study. For the hybrid manufacturing/remanufacturing production planning problem, the imprecision of customer demand, related operating costs, and the number of returned used components are considered to be the main uncertainty. As a result, the fuzzy set theory is employed due to the presence of the imprecise information. To defuzzify imprecise data, the Possibilistic Linear Programming (PLP) with the weighted average method is applied. The proposed approach maximizes the most likely value of the profit, minimizes the risk of obtaining a lower profit, and maximizes the possibility of obtaining a higher profit for each production planning policy at the same time. The result shows that the Priority-To-Remanufacturing (PTR) policy shows a higher profit from each objective function and is solved with a higher satisfaction value than the policy of giving more Priority-To-Manufacturing (PTM). For instance, the most likely profits of the PTR policy from each scenario are ranging from $ 66,774 to $ 114,280 as compared to $ 66,610 to $ 88,882 from the PTM policy and a higher satisfaction values of the linear membership function are ranging from 38.34% to 53.95% from the PTR policy as compared to 39.13% to 53.40% from the PTM policy. As a result, PLP can help decision makers to be well aware of the risks and effects of uncertainty on their plans, so they can prepare in advance for such scenarios.**

***Index Terms*—Optimization, Hybrid manufacturing/remanufacturing, Possibilistic Linear Programming.**

I. INTRODUCTION

Many products such as electrical apparatus, toner cartridges, cellular phones, and automotive parts require remanufacturing for recovering components as raw materials to produce finished products [1]. Because of limited resources, remanufacturing of these used products is significantly growing in many countries. According to the Carbon Trust news, remanufacturing in the UK had a market potential of up to £5.6 billion, with benefits to improve business revenues, margins, and stability of supply [2].

Remanufacturing includes the processes of disassembly, cleaning, inspection, and sorting of used products before reassembling to new parts or new products. It can be divided into two groups. First, a stand-alone remanufacturing system is concerned with used products that are supplied for all demands. Second, a hybrid manufacturing/remanufacturing system can be used when remanufacturing is required to work along with the existing manufacturing processes where new components may only be required when there is a shortage of old or used components.

In remanufacturing processes, the uncertainty of quantity, timing, and quality of receiving used products dramatically increases the difficulty of production planning and inventory management. Planners need to make decisions on how many new components or how many used products are required and especially on when such orders should be placed. Moreover, customer demand and related operating costs are very much subject to uncertainty. Customer demand normally varies with time due to errors in forecasting, or lack of information while certain operating costs are difficult to be fixed in advance. To handle such issues, a certain approach can be used to optimize such problems under the uncertainty. Instead of using a typical linear programming where the uncertainty is disregarded, Possibilistic Linear

Programming (PLP) is one of the approaches that can be used to incorporate fuzzy data and optimize a problem. Our main contribution is to introduce the Possibilistic Linear Programming (PLP) model to optimize the profit of the production and inventory planning in a hybrid manufacturing/remanufacturing system can then recommend the best policy between the Priority-To-Remanufacturing (PTR) and Priority-To-Manufacturing (PTM) in an uncertain environment. A sensitivity analysis is carried out with many scenarios to investigate the effects of each policy under the different levels of weight for pessimistic, most likely or optimistic conditions.

The remaining paper is presented as follows. Section 2 presents a literature review. Section 3 shows the methodology for solving the stochastic model based on the Possibilistic Linear Programming model. Section 4 presents a case study of inventory control and optimization in a hybrid manufacturing/ remanufacturing in an uncertain environment. Next, Section 5 shows the results and discussion. Section 6 then presents the conclusion.

II. Literature review

Lund (1985) illustrated remanufacturing as "an industrial process in which worn-out products are restored to like-new condition" [3]. The remanufacturing industry boomed during World War II because of insufficient resources. The automotive (industrial) sector has the most experience in remanufacturing [1]. Remanufacturing is a product recovery option. There are many recovery options such as reusing, repairing, refurbishing, and recycling [4]. Remanufacturing is a direct form of reuse that combines returned products, to resell them again like new products. The remanufacturing process can be separated into disassembling the returned products, cleaning disassemble parts, replacing or repairing any worn or damaged components, testing the quality of products, updating some parts of electro-electronic products, and reassembling the products. Products that pass remanufacturing testing can be considered to have the quality of "like-new" products [5].

According to [6], remanufacturing is normally managed under two business strategies: combined and dedicated models. The combined model is mostly applied in European countries. Remanufacturing and manufacturing are combined in the same line as a hybrid process. In contrast, the dedicated model is mostly applied in North America. It is considered a standalone remanufacturing line. For production planning and inventory control problems, attention is placed on different inventory policies such as periodic and continuous reviews. There are many complicated characteristics of remanufacturing such as the uncertain quality of returns and the need to balance the returns and new components with customer demand. Inderfurth demand found that the optimal inventory control policy for the hybrid manufacturing/remanufacturing system under strictly proportional costs and revenues is the order-up-to policy [7]. The system is constructed in a single-period with stochastic returns of used products and customer demand, to substitute remanufactured products with manufactured products when a shortage occurs. Wang investigated the optimal production strategy for short life cycle products with stochastic returned products and customer demand [8]. The objective was to minimize the total costs of this system. The optimal total costs are incurred when applying a mixed strategy, which is a mixture of remanufacturing, manufacturing, and disposal simultaneously. A significant decrease in the total cost can be obtained by setting the suitable values of manufactured products and the ratio of remanufactured products to returned products.

With the complication of inventory control policies, the optimal settings for the operating parameters in an inventory policy are required to obtain the maximum profit of the system. Optimization can be carried out by either analytical or heuristics models. The analytical models always give global optimal solutions but consume a longer running time. The heuristics optimization may provide only local optimal solutions, which can be good enough solutions, with a shorter running time. Proper solving method selection is a trade-off between solution quality and computational time. In addition, analytical models need the simplification of assumptions and provide static results. Without the uncertainties, solutions are compromised in real-world problems. Hence, the fuzzy logic is introduced to take care of uncertainties and to provide results that, can reflect real-world problems. As a result, fuzzy linear programming can provide practical optimal results under realistic circumstances [9].

In practice, input data or related parameters for production planning and control problems are imprecise/fuzzy, such as costs of operations, customer demand, and number of returned products. These imprecise/fuzzy data occur because some information is incomplete or uncontrollable. These problems cannot be solved and optimized by a traditional mathematical analytical model such as linear programming becasue it only operates under deterministic circumstances. To incorporate the uncertainty, introduced the fuzzy set theory into traditional linear programming problems. His study considered linear programming problems with fuzzy goals and constraints [10]. presented the theory of possibility, which is related to the theory of fuzzy sets by applying the concept of a possibility distribution as a fuzzy restriction, acting as an elastic constraint [11]. In addition, presented Possibilistic Linear Programming (PLP) in standard form with no equality constraints [12]. Then, applied two-phase PLP combined with the

fuzzy Analytical Hierarchical Process (AHP) to optimize multi-objective linear programming [13]. Our study applies the PLP approach for solving the production planning and inventory control policy for hybrid manufacturing/remanufacturing with imprecise forecast demand, related operating costs, and number of returned components. The proposed approach attempts to maximize the most likely value of the imprecise total profits, minimize the risk of obtaining a lower profit, and maximize the possibility of obtaining higher profits for each policy simultaneously. This approach can provide realistic results, which are better than a typical deterministic approach as it can handle fuzzy data and recommend a range of possible optimal objective values. This helps decision makers to be aware of possible outcomes in all scenarios from the most likely, optimistic, and pessimistic cases. Therefore, decision makers can well prepare themselves in advance for such scenarios

III. Methodology

Two optimization solving methods are introduced to measure their performances on a hybrid manufacturing/remanufacturing system in an uncertain environment. The system is modeled with both deterministic and stochastic conditions, using

Mixed-Integer Linear Programming (MILP) and Possibilistic Linear Programming (PLP), respectively. Fig. 1 shows the approach for each solving method.

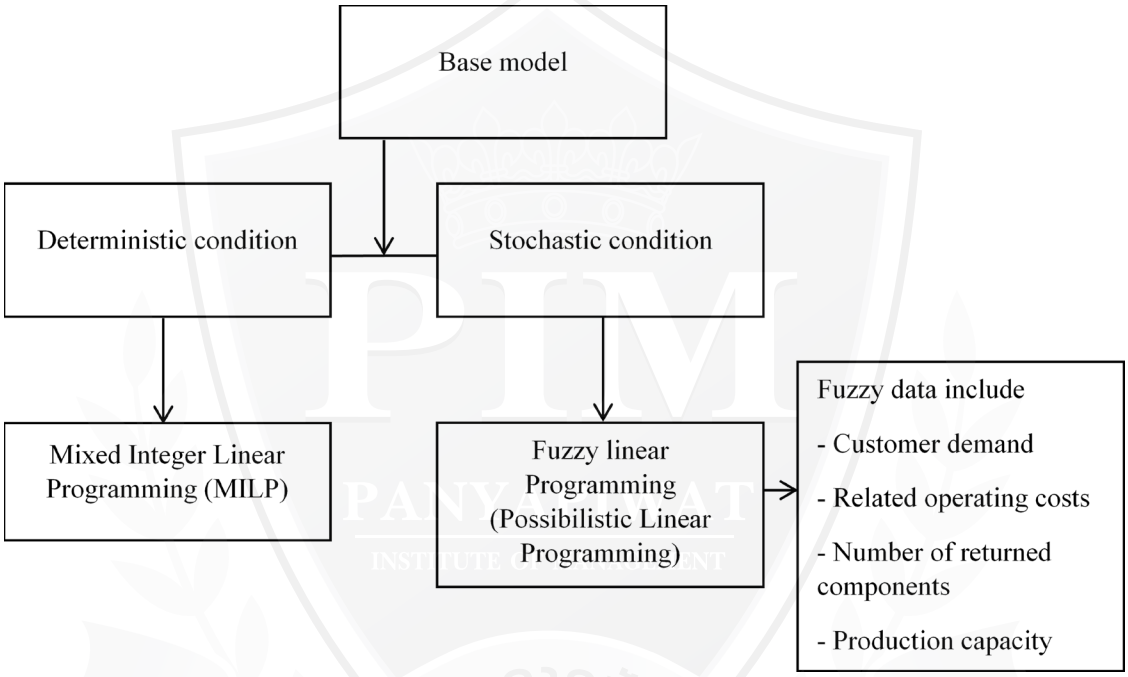


Fig. 1. Method of approach.

A. Deterministic condition using MILP

The system is modeled, and the profit of the model is optimized using MILP. There is no uncertainty in this situation. As a result, the ideal solution from this method is be used as a benchmark for a comparison.

B. Stochastic condition using PLP

The PLP method can handle a problem with uncertainty. An uncertain environment in this case contains uncertain customer demand in each week, related operating costs, and number of arriving returned components in each week. The PLP converts these uncertain/fuzzy data to crisp data. There are four main steps to solve the PLP:

1) Model the uncertainty data with triangular (possibility) distribution

Figure 2 presents the triangular distribution of an uncertain coefficient $\tilde{x} = \left(x^P, x^M, x^O\right)$.. In general, the triangular distribution is based on the three important data values as follows.

1.1) The most pessimistic value (x^P) that has the lowest possibilistic degree for the set of available values (possibilistic degree = 0)

1.2) The most likely value (x^M) that has the highest possibilistic degree for the set of available values (possibilistic degree = 1)

1.3) The most optimistic value (x^O) that has the lowest possibilistic degree for the set of available values (possibilistic degree = 0)

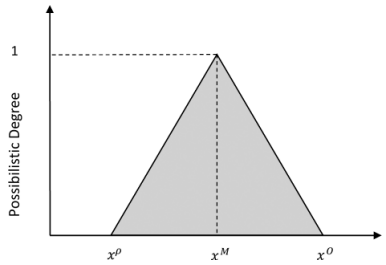


Fig. 2. Triangular possibility distribution of $\tilde{x}$

2) Develop three new crisp objective functions of multi objective linear programming (MOLP)

The imprecise objective function in this model has a triangular distribution $\tilde{z} = (z^P, z^M, z^O)$. This imprecise objective function is defined by three important points $(z^P, 0)$,$(z^M, 1)$, and $(z^O, 0)$. The imprecise objective can be maximized by pushing three important points to the right. Because the vertical coordinate of important points is fixed at either 1 or 0, only three horizontal coordinates are considered. Solving the imprecise objective requires simultaneously maximizing z^P, z^M, and z^O. Instead of simultaneously maximizing z^P, z^M, and z^O, the proposed approach maximizes the profit z^M, minimizes the range of the profit of (z^M-z^P) and, maximizes the range of the profit of (z^O- z^M). This proposed approach involves maximizing the most likely value of the imprecise total profit z^M, minimizing the risk of obtaining a lower profit (z^M-z^P), and maximizing the possibility of obtaining a higher profit (z^O- z^M). Fig. 3 presents the strategy for maximizing the imprecise objective functions.

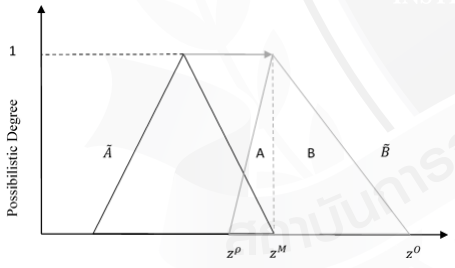


Fig. 3. Strategy for maximizing the imprecise objective function

As presented in Fig. 3, the possibility distribution $\tilde{A}$ is preferred to the possibility distribution $\tilde{B}$. The results for three new crisp objective functions are presented as follows:

$$\text{Max } z_1 = z^M \quad (1)$$
$$\text{Min } z_2 = (z^M - z^P) \quad (2)$$
$$\text{Max } z_3 = (z^O - z^M) \quad (3)$$

Equation (1) to Equation (3) are equivalent to simultaneously maximizing the most likely value of the total profit, minimizing the risk of obtaining a lower profit (area A of the possibility distribution in Fig. 3), and maximizing the possibility of obtaining a higher profit (area B of the possibility distribution in Fig. 3).

3) Convert uncertainty constraints into crisp constraints using the weighted average method

We consider the situation where the number of returned products, related operating costs, and customer demand are uncertain and have the triangular distribution with the most likely and least possible values. The problem is to obtain crisp numbers for the uncertainty of the number of returned products, related operating costs, and customer demand by applying the weighted average method to convert them into crisp values, where w_1, w_2, and w_3 denote the weight of the pessimistic, most likely, and optimistic cases respectively. The weights w_1, w_2, and w_3 can be determined by the experience of decision makers and $w_1 + w_2 + w_3 = 1$.

4) Specify the linear membership functions for three new objective functions, and then convert the auxiliary MOLP problem into an equivalent linear programming model using the fuzzy decision method

4.1) Find the lower bound and the upper bound of each objective

To convert the auxiliary MOLP problem into an equivalent single-goal linear programming problem, the fuzzy decision method from [10], and the [14]. fuzzy programming method are employed. The Negative Ideal Solution (NIS) and Positive Ideal Solution (PIS) of three objective functions from step two are required. Three new crisp objective functions of the multi objective linear programming can be stated as follows:

$$z_1^{PIS} = \max z^M,\ z_1^{NIS} = \min z^M \quad (4)$$
$$z_2^{PIS} = \min (z^M - z^P),\ z_2^{NIS} = \max (z^M - z^P) \quad (5)$$
$$z_3^{PIS} = \max (z^O - z^M),\ z_3^{NIS} = \min (z^O - z^M) \quad (6)$$

4.2) Find the corresponding linear membership function of each objective function

The corresponding linear membership function for each objective function is defined by

$$f1(z1) = \begin{cases} 1 & , z_1 < z_1^{PIS}, \\ \dfrac{z_1 - z_1^{NIS}}{z_1^{PIS} - z_1^{NIS}} & , z_1^{NIS} \le z_1 \le z_1^{PIS}, \\ 0 & , z_1 > z_1^{NIS}, \end{cases} \quad (7)$$

$$f2(z2) = \begin{cases} 1 & , z_2 < z_2^{PIS}, \\ \dfrac{z_2^{NIS} - z_2}{z_1^{NIS} - z_2^{PIS}} & , z_2^{PIS} \le z_2 \le z_2^{NIS}, \\ 0 & , z_2 > z_2^{NIS} \end{cases} \quad (8)$$

$$f3(z3) = \begin{cases} 1 & , \overline{z_3} < z_3^{PIS}, \\ \dfrac{z_3 - z_3^{NIS}}{z_3^{PIS} - z_3^{NIS}} & , z_3^{NIS} \le z_3 \le z_3^{PIS}, \\ 0 & , z_3 > z_3^{NIS}. \end{cases} \quad (9)$$

Each linear membership function can be obtained by using a case study to specify an imprecise objective value in an interval (0-1). Fig. 4. shows a graph of the linear membership functions for Equation (7) and Equation (9). Fig. 5. shows a graph of the linear membership functions for Equation (8).

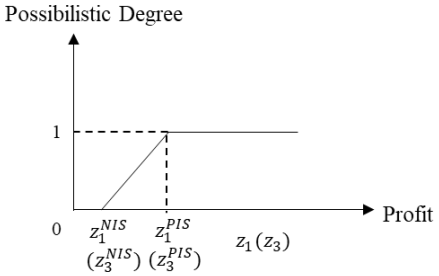


Fig. 4. Linear membership function of z_1 and z_3.

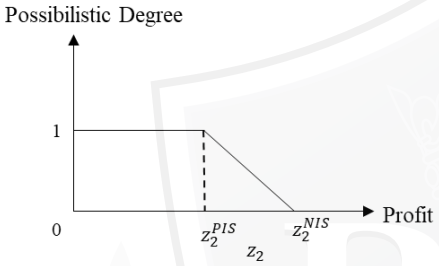


Fig. 5. Linear membership function of z_2.

4.3) Find the maximum overall satisfaction

The fuzzy decision method from [10]., and [14]. is used to formulate a single goal linear programming model, which is minimax of the satisfaction values from the three above mentioned objective functions.

Max λ

Subject to

$\lambda \leq f_i(z_i)$, i = 1,2,3

$0 \leq \lambda \leq 1$

i = number of linear membership functions of each objective.

IV. Case Study

For this case study of production planning and inventory control optimization in a hybrid manufacturing/remanufacturing in an uncertain environment, Fig. 6 shows a flow diagram of the system. It requires two types of components for production: new components and returned components. Returned components indicate the used parts that are returned from customers. Returned components use the reorder cycle policy to control their inventory, as returned components come in a batch at the beginning of each week. A certain percentage of returned components need to be disposed of to prevent excess inventory. Accepted returned components are then kept in a Returned Component Inventory (RCI), pending for the remanufacturing processes. It is assumed that the remanufacturing time of the returned components is negligible. However, the remanufacturing cost per unit can be more expensive than the manufacturing cost per unit depending the quality of the returned components as poor-quality components could incur more expense to produce.

There is also a New Component Inventory (NCI), which is also reviewed every week. The ordering lead time for the new components is constant at one week. Upon arrival, these new components are kept in the NCI before they are used in the manufacturing processes. One calendar week is considered for a manufacturing week. Finished products are then kept in a Finished Product Inventory (FPI), waiting for the customer demand.

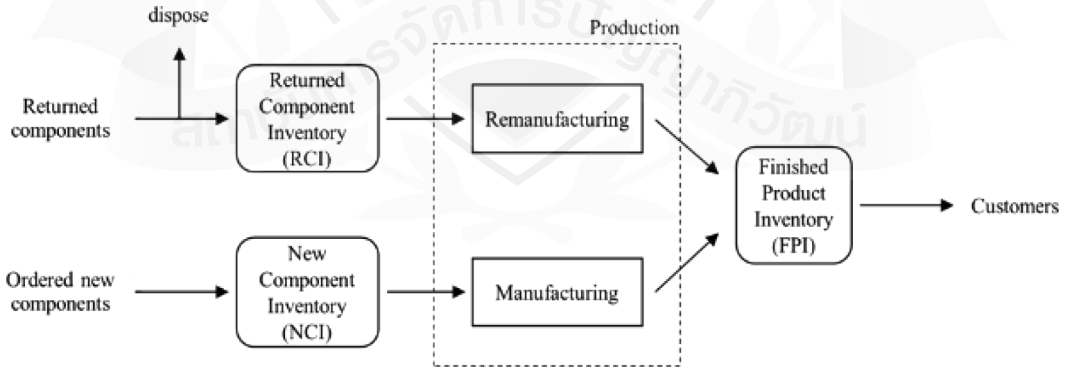


Fig. 6. General flowchart of the studied system.

Customer demand arrives every week. Lost sales cost incurs when there are not enough finished products. Otherwise, customers buy the finished products from the FPI. For finished products, the quality from manufacturing and remanufacturing is considered to be the same. When the inventory level of the FPI is reduced, the system requests for the production. The purpose is to fill back the inventory level of the FPI. The initial inventory quantity is set to be equal to the FPI target inventory level, which is one of the decision variables. Two inventory control policies (Priority-To-Remanufacturing vs Priority-To-Manufacturing) are experimented here to decide which process (remanufacturing vs

manufacturing) has a higher priority. As shown in Fig. 7, the operation flow of each policy is shown as follows:

A. Priority-To-Remanufacturing (PTR)

With priority-to-remanufacturing, returned components are assigned with a higher priority than new components unless they are not available. Manufacturing production is provoked only when there are not enough returned components in the RCI. The interested controlled decision variables in this policy include Disposal Rate (disR), Target Inventory Level of NCI (TinvN), and Target Inventory Level of FPI (TinvF). Certain returned components are disposed of depending on disR. Then, new components are ordered up to TinvN in every review cycle (a week). The initial inventory level of NCI is set to be equal to TinvN. When finished products are sent to customers, upstream components are pulled to replenish the taken products by filling the FPI back to TinvF where the initial inventory level of FPI is equal to TinvF.

B. Priority-To-Manufacturing (PTM)

In contrast to PTR, new components are assigned with a higher priority over returned components. Returned components are used for production only when there is a shortage of new components. Inventories are regulated by the decision variables, similar to PTR.

The system is investigated for one year or (50 weeks). With 5 days a week and 8 hours a day, there are 40 hours a week. Table 1 presents the cost structure. Other relevant information is described below.

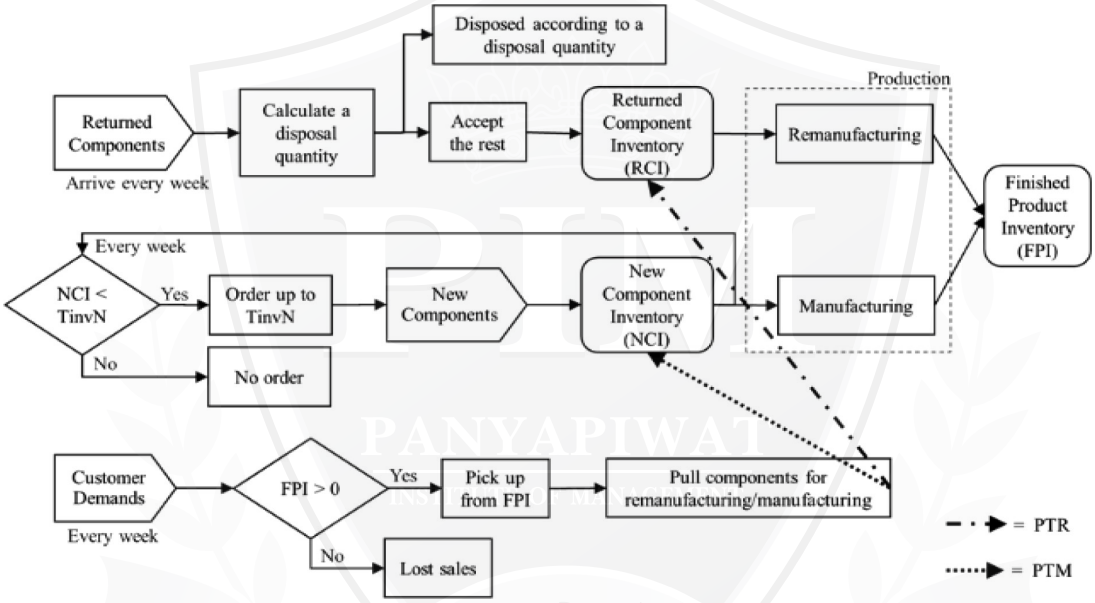


Fig. 7. Flow diagram of the PTR and the PTM policies.

C. Other relevant information

1) The maximum levels of the target inventory for new component inventory and finished product inventory depend on the maximum of production capacity, which is subject to uncertainty.

2) The overall customer service level in this case study is set to at least 85%.

3) The returned component ratio is set at 0.6: This ratio presents arriving returned components per total customer demand. Both arriving returned components and total customer demand distribute under the normal distribution in an uncertain environment. The means and standard deviations for the arriving returned components is 60 and 10 units per week, consecutively and for total customer demand is 100 and 20 units per week, consecutively.

4) A supplier has the ability to send new components, but not more than 60 units per week.

5) The holding cost is 40% per year for a unit (i.e., new component cost, returned component preparation cost, finished product cost). It is assumed that the finished product holding costs per unit of both manufacturing (FHm_y) and remanufacturing (FHr_y) products are the same based on the average unit cost value from both types of products.

6) The symbol "~" refers to ambiguous data that are determined to be fuzzy in this study

TABLE I
COST STRUCTURE

Parameters	Notation	Cost ($ per unit)
Returned component disposal cost	RD_u	0
New component cost	NC_u	(26,30,35)
Returned component preparation cost	RP_u	(4,5,7)
Manufacturing cost	MM_u	(9,10,13)
Remanufacturing cost	RM_u	((9*(2-y), (10*(2-y)), (13*(2-y)) *
Returned component holding cost	RH_y	(1.6,2,2.4) per year
New component holding cost	NH_y	(10,12,15) per year
Finished product holding cost (from returned components)	FHr_y	(9.5,11,14) per year
Finished product holding cost (from new components)	FHm_y	(9.5,11,14) per year
Lost sales cost	LS_u	(45,50,58)
Sales price	$Price_u$	(45,50,58)

Remark: * y is the yield of returned components, which is set equal to (0.3,0.65,1). For example, the remanufacturing cost of the most likely case is calculated as (10*(2-0.65)) = $ 13.5 per unit.

LP formulation (Deterministic case)

The mathematical model presented in this case study is formulated as the linear programming model. Notations and the formulation of the analytical model are presented below where t refers to the time in weeks, ranging from 1 to 50.

D. Parameters

ReA_t = Arriving returned components in week t
$dispose_t$ = Returned components (disposed of) in week t
$R0_t$ = Returned components accepted to inventory in week t
RCI_t = Ending inventory level in the Returned Component Inventory (RCI) in week t
$R1_t$ = Returned components sent to remanufacturing in week t
$R2_t$ = Finished products from remanufacturing in week t
$FPIr_t$ =Ending inventory level in Finished Product Inventory (FPI) from remanufacturing in week t
$R3_t$ = Finished products from remanufacturing sent to customer in week t
$order_t$ = New components ordered in week t
NCI_t = Ending inventory level in the New Component Inventory (NCI) in week t
$M1_t$ = New components sent to manufacturing in week t
$M2_t$ = Finished products from manufacturing in week t
$FPIm_t$ = Ending inventory level in the Finished Product Inventory (FPI) from manufacturing in week t
$M3_t$ = Finished products from manufacturing sent to customer in week t
FPI_t = Ending inventory level in the Finished Product Inventory (FPI) in week t
D_t = Customer demand in week t
LS_t = Lost sales in week t
PC_t = Production capacity to produces a product in week t

Cost parameters ($)

RD = Total returned component disposal cost
LS = Total lost sales cost
RMM = Total remanufacturing and manufacturing cost
NC = Total new component cost
RP = Total returned component cost
CH = Total component holding cost
FH = Total finished product holding cost
TC =Total costs
$Revenue$ = Total income from selling finished products
$Profit$ = Total income after deducting total costs

E. Decision Variables

$TinvN$ = Target inventory level in NCI (unit)
$TinvF$ = Target inventory level in FPI (unit)
$disR_t$ = Disposal rate in week t (%)

F. Objective Function:

$$Maximize\ Profit = Revenue - TC \tag{10}$$

subject to
inventory balance constraints:

$$ReA_t = (disR_t * ReA_t) + R0_t \quad for\ all\ t \tag{11}$$

$$R2_t = R1_t \quad for\ all\ t \tag{12}$$

$$M2_t = \begin{cases} 0 & where\ t = 1 \\ M1_{t-1} & where\ t = 2\ to\ t = 50 \end{cases} \tag{13}$$

$$R3_t + M3_t + LS_t = D_t \quad for\ all\ t \tag{14}$$

$$FPI_t = FPIr_t + FPIm_t \quad for\ all\ t \tag{15}$$

$$PC_t \geq R1_t + M1_t \quad for\ all\ t \tag{16}$$

$$RCI_t = \begin{cases} R0_t - R1_t & where\ t = 1 \\ RCI_{t-1} + R0_t - R1_t & where\ t = 2\ to\ t = 50 \end{cases} \tag{17}$$

$$NCI_t = \begin{cases} TinvN - M1_t & where\ t = 1 \\ NCI_{t-1} + order_{t-1} - M1_t & where\ t = 2\ to\ t = 50 \end{cases} \tag{18}$$

$$FPIr_t = \begin{cases} R2_t - R3_t & where\ t = 1 \\ FPIr_{t-1} + R2_t - R3_t & where\ t = 2\ to\ t = 50 \end{cases} \tag{19}$$

$$FPIm_t = \begin{cases} TinvF - M3_t & where\ t = 1 \\ FPIm_{t-1} + M2_t - M3_t & where\ t = 2\ to\ t = 50 \end{cases} \tag{20}$$

where ReA_t, and D_t are uncertainty coefficients with the triangular distribution. The objective function (constraint (10)) is to maximize the profit. Constraint (11) and Constraint (12) are inventory balance constraints. For Constraint (11), some of the returned components are disposed of depending on the disposal rate in every week, and the rest is sent to the Returned Component Inventory (RCI). Constraint (12) ensures that the quantity of returned components sent to remanufacturing processes are the same quality as the finished products coming out of the remanufacturing processes within the same week and the remanufacturing time is negligible. Constraint (13) states that the manufacturing lead time is one week. For Constraint (14), customer demand is satisfied by the finished products, otherwise, lost sales occur. For Constraint (15), total units of finished products in manufacturing and remanufacturing are combined in the FPI. Constraint (16) describes the constraint of production capacity for remanufacturing and manufacturing, in which the number of components sent to the manufacturing process must be less than or equal to the production capacity. Constraints (17) to (20) describe the constraints for returned components, new components, and finished products for remanufacturing and manufacturing. The ending inventory is equal to the previous ending inventory (week) plus the incoming inventory minus the outgoing inventory. In the first week, the ending inventory is equal to the incoming inventory minus the outgoing inventory.

G. The PTR constraints:

$$RCI_t = \begin{cases} 0 & if\ D_t \geq R0_t & where\ t = 1 \\ 0 & if\ D_t \geq R0_t + RCI_{t-1} & where\ t = 2\ to\ t = 50 \\ any\ integers & otherwise & for\ all\ t \end{cases} \tag{21}$$

$$R0_t = \begin{cases} D_t & if\ D_t < ReA_t & for\ all\ t \\ ReA_t & if\ ReA_t < D_t & for\ all\ t \end{cases} \tag{22}$$

$$R1_t = \begin{cases} D_t & if\ D_t < R0_t + RCI_{t-1} & for\ all\ t \\ any\ integers & otherwise & for\ all\ t \end{cases} \tag{23}$$

where ReA_t, and D_t are uncertain coefficients with the triangular distribution. Constraints (21) and (23) describe the policies of the PTR. All returned components in RCI are sent to remanufacturing when the customer demand is greater than the incoming returned components plus the number of the previous week's ending inventory. Otherwise the number of returned components sent to remanufacturing is equal to the customer demand.

H. The PTM constraints

$$NCI_t = \begin{cases} 0 & if\ D_t \geq TinvN \quad where\ t = 1 \\ order_{t-1} & if\ D_t \geq NCI_{t-1} \quad where\ t = 2\ to\ t = 50 \\ any\ integers & otherwise \quad for\ all\ t \end{cases} \tag{24}$$

$$M1_t = \begin{cases} D_t & if\ D_t < NCI_{t-1} \quad for\ all\ t \\ any\ integers & otherwise \quad for\ all\ t \end{cases} \tag{25}$$

where D_t are uncertain coefficients with the triangular distribution. Constraints (24) and (25) describe the policies of the PTM, where the number of new components in the NCI that is sent to manufacturing is equal to the customer demand when it is less than the number of new components. Otherwise, all of the returned components are sent to manufacturing. The ending level of inventory in the NCI is equal to the incoming orders from the previous week when the customer demand is greater than the previous period's ending inventory level.

I. Economic constraints

$$RD = \sum_t RD_u * dispose_t \quad for\ all\ t \tag{26}$$

$$LS = \sum_t LS_u * LS_t \quad for\ all\ t \tag{27}$$

$$RMM = \sum_t RM_u * R1_t + \sum_t MM_u * M1_t + MM_u * TinvF \quad for\ all\ t \tag{28}$$

$$NC = \sum_t NC_u * \left(order_t + initial\ NCI + TinvF\right) \quad for\ all\ t \tag{29}$$

$$RP = \sum_t RP_u * R0_t \quad for\ all\ t \tag{30}$$

$$CH = \left(\frac{RH_y}{50} * \left(R0_1 + RCI_1\right)\right)/2 + \sum_{t=2}^{50}\left(\frac{RH_y}{50} * \left(R0_t + RCI_{t-1} + RCI_t\right)\right)/2 + \left(\frac{NH_y}{50} * \left(initial\ NCI + NCI_1\right)\right)/2 + \sum_{t=2}^{50}\left(\frac{NH_y}{50} * \left(order_{t-1} + NCI_{t-1} + NCI_t\right)\right)/2 \tag{31}$$

$$FH = \left(\frac{FHr_y}{50} * \left(R2_1 + FPIr_1\right)\right)/2 + \sum_{t=2}^{50}\left(\frac{FHr_y}{50} * \left(R2_t + FPIr_{t-1} + FPIr_t\right)\right)/2 + \left(\frac{FHm_y}{50} * \left(M2_1 + TinvF + FPIm_1\right)\right)/2 + \sum_{t=2}^{50}\left(\frac{FHm_y}{50} * \left(M2_t + FPIm_{t-1} + FPIm_t\right)\right)/2 \tag{32}$$

$$TC = RD + LS + RMM + NC + RP + CH + FH \tag{33}$$

$$Revenue = \sum_t Price_u * \left(R3_t + M3_t\right) \quad for\ all\ t \tag{34}$$

$$Profit = Revenue - Total\ costs \tag{35}$$

where LS_t, RM_u, MM_u, NC_u, RP_u, NH_y, RH_y, FHr_y, FHm_y, and $Price_u$ are uncertain coefficients with the triangular distribution. Constraints (26) to (32) describe the cost parameters to calculate the total cost (TC). The TC consists of the Returned Component Disposal Cost (RD), Lost Sales Cost (LS), Remanufacturing and Manufacturing Cost (RMM), New Component Cost (NC), Returned Component Preparation Cost (RP), Component Holding Cost (CH), and Finished Product Holding Cost (FH). All holding costs are calculated based on the average level of inventory. Constraint (35) states that the profit is calculated by the revenue (Constraint (34)) minus total costs (Constraint (33)).

Decision Variables:

$$order_t = TinvN \quad NCI_t \quad for\ all\ t \tag{36}$$

$$R1_t + M1_t = TinvF - FPI_t \quad for\ all\ t \tag{37}$$

$$disR_t = 100 * (dispose_t / ReA_t) \quad for\ all\ t \tag{38}$$

For Equation (36), the order of new components depends on $TinvN$. Equation (37) shows that the total

number of new and returned components sent to production equal the number of finished products. Equation (38) describes the disposal rate, which is the percentage of disposed of components over the returned components.

Possibilistic Linear Programming (PLP)

We develop the possibilistic linear programming method to solve this problem under uncertainty by developing three new crisp objective functions of the multi-objective linear programming (MOLP) to replace Equations (1)-(3)

$$\text{Max } z_1 = Profit^M = Revenue^M - TC^M$$
$$= Revenue^M - RD^M + LS^M + RMM^M + NC^M + RP^M + CH^M + FH^M \quad (39)$$
$$\text{Min } z_2 = Profit^{P-M} = Revenue^{P-M} - TC^{P-M}$$
$$= Revenue^{P-M} - RD^{P-M} + LS^{P-M} + RMM^{P-M} + NC^{P-M} + RP^{P-M} + CH^{P-M} + FH^{P-M} \quad (40)$$
$$\text{Max } z_3 = Profit^{M-O} = Revenue^{M-O} - TC^{M-O}$$
$$= Revenue^{M-O} - RD^{M-O} + LS^{M-O} + RMM^{M-O} + NC^{M-O} + RP^{M-O} + CH^{M-O} + FH^{M-O} \quad (41)$$

As the demand of customers, quantity of returned components, and related operation cost are fuzzy, a defuzzification method using the weighted average method is applied to solve the imprecise data.

Constraint (11), (14), (16), (21), (22), (23), (24), and (25) need to be transformed to crisp constraints as follows:

$$w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O = dispose_t + R0_t \quad for\ all\ t \quad (42)$$

$$R3_t + M3_t + LS_t = w_1 d_t^P + w_2 d_t^M + w_3 d_t^O \quad for\ all\ t \quad (43)$$

$$w_1 PC_t^P + w_2 PC_t^M + w_3 PC_t^O \geq R1_t + M1_t \quad for\ all\ t \quad (44)$$

$$RCI_t = \begin{cases} 0 \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \geq R0_t & where\ t = 1 \\ 0 \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \geq R0_t + RCI_{t-1} & where\ t = 2\ to\ t = 50 \\ any\ integers \quad otherwise & for\ all\ t \end{cases} \quad (45)$$

$$R0_t = \begin{cases} w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \\ if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O < w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O \quad for\ all\ t \\ w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O \\ if\ w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O \leq w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \quad for\ all\ t \end{cases} \quad (46)$$

$$R1_t = \begin{cases} w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \\ if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O < R0_t + RCI_{t-1} \quad for\ all\ t \\ any\ integers \quad otherwise \quad for\ all\ t \end{cases} \quad (47)$$

$$NCI_t = \begin{cases} 0 & if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \geq TinvN & where\ t = 1 \\ order_{t-1} & if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \geq NCI_{t-1} & where\ t = 2\ to\ t = 50 \\ any\ integers & otherwise & for\ all\ t \end{cases} \quad (48)$$

$$M1_t = \begin{cases} w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O < NCI_{t-1} \quad for\ all\ t \\ any\ integers \quad otherwise \quad for\ all\ t \end{cases} \quad (49)$$

where $w_1 + w_2 + w_3 = 1$ and the weights of w_1, w_2, and w_3 can be determined by the experience and knowledge of decision makers.

The linear membership functions for three new objective functions are specified, and we convert the auxiliary MOLP problem into an equivalent linear programming model by the fuzzy decision method.

To find the Negative Ideal Solution (NIS) and the Positive Ideal Solution (PIS) of each objective, the fuzzy decision method as presented in Equations (4) to (6) is introduced to solve MOLP by finding the corresponding linear membership function of each objective function.

$$z_1^{PIS} = \max Profit^M \quad , \quad z_1^{NIS} = \min Profit^M \quad (50)$$

$$z_2^{PIS} = \min Profit^{P-M} \quad , \quad z_2^{NIS} = \max Profit^{P-M} \quad (51)$$

$$z_3^{PIS} = \max Profit^{M-O} \quad , \quad z_3^{NIS} = \min Profit^{M-O} \quad (52)$$

Equations (7) to (9) are applied to the corresponding linear membership functions for each objective function in this case study as follows:

$$f1(z1)=\begin{cases}1 & , \quad z_1 < z_1^{PIS},\\ \dfrac{z_1 - z_1^{NIS}}{z_1^{PIS} - z_1^{NIS}} & , \quad z_1^{NIS} \le z_1 \le z_1^{PIS},\\ 0 & , \quad z_1 > z_1^{NIS},\end{cases}$$

$$f2(z2)=\begin{cases}1 & , \quad z_2 < z_2^{PIS},\\ \dfrac{z_2^{NIS} - z_2}{z_1^{NIS} - z_2^{PIS}} & , \quad z_2^{PIS} \le z_2 \le z_2^{NIS},\\ 0 & , \quad z_2 > z_2^{NIS},\end{cases}$$

$$f3(z3)=\begin{cases}1 & , \quad z_3 < z_3^{PIS},\\ \dfrac{z_3 - z_3^{NIS}}{z_3^{PIS} - z_3^{NIS}} & , \quad z_3^{NIS} \le z_3 \le z_3^{PIS},\\ 0 & , \quad z_3 > z_3^{NIS}.\end{cases}$$

Find the maximum overall satisfaction:
Max λ
Subject to
$\lambda \le f_i(z_i)$, where i = 1,2,3
i = number of linear membership function of each objective.
$0 \le \lambda \le 1$

$$w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O = dispose_t + R0_t \quad for\ all\ t,$$

$$R2_t = R1_t \quad for\ all\ t,$$

$$R3_t + M3_t + LS_t = w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \quad for\ all\ t,$$

$$FPI_t = FPIr_t + FPIm_t \quad for\ all\ t,$$

$$w_1 PC_t^P + w_2 PC_t^M + w_3 PC_t^O \ge R1_t + M1_t \quad for\ all\ t,$$

$$RCI_t = \begin{cases} R0_t - R1_t & where\ t = 1,\\ RCI_{t-1} + R0_t - R1_t & where\ t = 2\ to\ t = 50,\end{cases}$$

$$NCI_t = \begin{cases} TinvN - M_t & where\ t = 1,\\ NCI_{t-1} + order_{t-1} - M1_t & where\ t = 2\ to\ t = 50,\end{cases}$$

$$FPIr_t = \begin{cases} R2_t - R3_t & where\ t = 1,\\ FPIr_{t-1} + R2_t - R3_t & where\ t = 2\ to\ t = 50,\end{cases}$$

$$FPIm_t = \begin{cases} TinvF - M3_t & where\ t = 1,\\ FPIm_{t-1} + M2_t - M3_t & where\ t = 2\ to\ t = 50,\end{cases}$$

For the PTR

$$RCI_t = \begin{cases} 0 \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \ge R0_t & where\ t = 1,\\ 0 \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \ge R0_t + RCI_{t-1} & where\ t = 2\ to\ t = 50,\\ any\ integers \quad otherwise & for\ all\ t,\end{cases}$$

$$R0_t = \begin{cases} w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \\ \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O < w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O \quad for\ all\ t \\ w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O \\ \quad if\ w_1 ReA_t^P + w_2 ReA_t^M + w_3 ReA_t^O < w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \quad for\ all\ t \end{cases}$$

$$R1_t = \begin{cases} w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \\ \quad if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O < R0_t + RCI_{t-1} \quad for\ all\ t \\ any\ integers \quad otherwise \quad for\ all\ t \end{cases}$$

For PTM

$$NCI_t = \begin{cases} 0 & if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \geq TinvN \quad where\ t = 1, \\ order_{t-1} & if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O \geq NCI_{t-1} \quad where\ t = 2\ to\ t = 50, \\ any\ integers & otherwise \quad for\ all\ t, \end{cases}$$

$$M1_t = \begin{cases} w_1 D_t^P + w_2 D_t^M + w_3 D_t^O & if\ w_1 D_t^P + w_2 D_t^M + w_3 D_t^O < NCI_{t-1} \quad for\ all\ t, \\ any\ integers & otherwise \quad for\ all\ t, \end{cases}$$

$$RD = \sum_t RD_u * dispose_t \quad for\ all\ t,$$

$$LS = \sum_t LS_u * LS_t \quad for\ all\ t,$$

$$RMM = \sum_t RM_u * R1_t + \sum_t MM_u * M1_t + MM_u * TinvF \quad for\ all\ t,$$

$$NC = \sum_t NC_u * \left(order_t + initial\ NCI + TinvF\right) \quad for\ all\ t,$$

$$RP = \sum_t RP_u * R0_t \quad for\ all\ t,$$

$$CH = \left(\frac{RH_y}{50} * \left(R0_1 + RCI_1\right)\right) / 2 + \sum_{t=2}^{50}\left(\frac{RH_y}{50} * \left(R0_t + RCI_{t-1} + RCI_t\right)\right) / 2 +,$$

$$\left(\frac{NH_y}{50} * \left(initial\ NCI + NCI_1\right)\right) / 2 + \sum_{t=2}^{50}\left(\frac{NH_y}{50} * \left(order_{t-1} + NCI_{t-1} + NCI_t\right)\right) / 2,$$

$$FH = \left(\frac{FHr_y}{50} * \left(R2_1 + FPIr_1\right)\right) / 2 + \sum_{t=2}^{50}\left(\frac{FHr_y}{50} * \left(R2_t + FPIr_{t-1} + FPIr_t\right)\right) / 2 +$$

$$\left(\frac{FHm_y}{50} * \left(M2_1 + TinvF + FPIm_1\right)\right) / 2 + \sum_{t=2}^{50}\left(\frac{FHm_y}{50} * \left(M2_t + FPIm_{t-1} + FPIm_t\right)\right) / 2,$$

$$TC = RD + LS + RMM + NC + RP + CH + FH,$$

$$Revenue = \sum_t Price_u * \left(R3_t + M3_t\right) \quad for\ all\ t,$$

$$Profit = Revenue - Total\ costs\ .$$

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V. Results and Discussion

5.1) Deterministic case with linear programming model

An LP model is built and solved by IBM ILOG CPLEX Optimization Studio software. The deterministic results of the PTR and the PTM policies are shown in Table II.

Table II compares the solutions obtained from these two policies. The result shows that the PTR policy is better than the PTM policy under the deterministic case, because the PTR policy shows a higher profit than the PTM policy. From the result, the PTR policy does not dispose of any returned components, but the PTM policy disposes of 75 units. This is due to the fact that the PTR policy requires that the returned components be used first while it this not a requirement for the PTM policy. Only the PTM policy has lost sales. This is because the PTR policy only requires remanufacturing, which does not require production time while the PTM policy requires the full production time. As a result, it would take a longer time to fill the FPI, which can cause lost sales and the PTM policy needs to keep a higher amount of inventory at FPI at the beginning of the first week, to prevent lost sales during the first week. However, it should be noted that the difference of the profit from these two policies is close, with less than a 4% gap.

TABLE II
PTR and PTM results

		Policy	
		PTR	PTM
Decision Variables	TinvN (units)	49	40
	TinvF (units)	39	166
	Number of units disposed (units)	0	75
Cost Parameters	LS ($)	0.00	50.00
	NC ($)	63,030.00	66,180.00
	RP ($)	15,380.00	15,005.00
	RMM ($)	62,046.00	62,174.00
	CH ($)	408.16	499.66
	FH ($)	782.76	592.79
	TC ($)	141,646.92	144,501.45
	Revenue ($)	256,400.00	256,350.00
	Profit ($)	114,753.08	111,849.05

5.2) Stochastic case with Possibilistic Linear Programming model (PLP)

With the lower bound and the upper bound of each objective (Constraints (50) to (52)), Tables 3-4 show the Negative Ideal Solution (NIS) and the Positive Ideal Solution (PIS) of each objective of the PTR and the PTM policies, respectively.

TABLE III
Upper and lower boundary of the PTR policy

PTR	
MOLP	Profit ($)
$z_1^{PIS} = \max Profit^M$	128,793.88
$z_1^{NIS} = \min Profit^M$	13,974.39
$z_2^{PIS} = \min Profit^{P-M}$	54,202.454
$z_2^{NIS} = \max Profit^{P-M}$	85,202.597
$z_3^{PIS} = \max Profit^{M-O}$	82,221.444
$z_3^{NIS} = \min Profit^{M-O}$	52,182.069

TABLE IV
Upper and lower boundary of the PTM policy

PTM	
MOLP	Profit ($)
$z_1^{PIS} = \max Profit^M$	125,372.9
$z_1^{NIS} = \min Profit^M$	0
$z_2^{PIS} = \min Profit^{P-M}$	52,917.918
$z_2^{NIS} = \max Profit^{P-M}$	86,251.638
$z_3^{PIS} = \max Profit^{M-O}$	82,903.386
$z_3^{NIS} = \min Profit^{M-O}$	51,129.002

According to Constraints (42) to (49) of the possibilistic linear programming model, the process of defuzzifying imprecise customer demand, number of arriving returned components, and production rate with the weighted average method is subject to the pattern of weight allocation. Different patterns of weight allocation can have an impact on the obtained solution. As a result, a sensitivity analysis of this weight allocation should be carried out among pessimistic, most likely, and optimistic cases to investigate the impact of such weight allocation on the overall satisfaction of the linear membership functions of each objective function. For a demonstration, a sensitivity analysis is performed in 4 scenarios by varying the weights of pessimistic, most likely, and optimistic values. Tables 5-6 present the results of the sensitivity analysis for both the PTR and the PTM policies.

TABLE V
RESULT OF THE SENSITIVITY ANALYSIS OF THE PTR POLICY

	Scenario I			Scenario II			Scenario III			Scenario IV		
	P	M	O	P	M	O	P	M	O	P	M	O
	33%	33%	33%	80%	10%	10%	10%	80%	10%	10%	10%	80%
Overall satisfaction	53.46%			38.34%			53.95%			40.08%		
Z1 ($)	109,350			66,774			114,280			99,616		
Z2 ($)	68,630			66,774			68,479			72,778		
Z3 ($)	68,241			63,701			68,388			71,421		
Maximum the most likely value of profit ($)	109,350			66,774			114,280			99,616		
Minimize the risk of obtaining lower profit ($)	40,720			0			45,801			26,838		
Maximize of the possibility of obtaining a higher profit ($)	177,591			130,475			182,668			171,037		

For example, in Table V with Scenario I, equal weights (33%) are assigned to the pessimistic, most likely, and optimistic values. It is found that the overall satisfaction is 53.46%, and the outcomes of the maximum most likely value of profit, minimum possibility of obtaining a lower profit, and maximum of the risk of obtaining a higher profit are $109,350, $40,720, and $177,591, respectively.

The result of this sensitivity analysis also shows that Scenario III, which set the weight of the most likely value at 80% and the weight of optimistic and pessimistic values at 10%, gives the highest overall satisfaction of 53.95%. Scenario III also gives the highest possible value of the most likely profit, obtaining the highest possibility of a higher profit and the highest profit from the risk of obtaining a lower profit.

However, the profit generated from Scenario IV, which is supposed to be the highest as it is the most optimistic case, is not the highest. This is due to the fact that the amount of optimistic demand is too high for the manufacturing process. As a result, a large shortage cost needs to be paid.

TABLE VI
RESULT OF THE SENSITIVITY ANALYSIS OF THE PTM POLICY

	Scenario I			Scenario II			Scenario III			Scenario IV		
	P	M	O	P	M	O	P	M	O	P	M	O
	33%	33%	33%	80%	10%	10%	10%	80%	10%	10%	10%	80%
Overall satisfaction	53.00%			39.13%			53.40%			42.40%		
Z1 ($)	84,866			66,610			88,882			73,055		
Z2 ($)	68,586			66,610			68,450			72,117		
Z3 ($)	67,968			63,562			68,098			69,531		
Maximum the most likely value of profit ($)	84,866			66,610			88,882			73,055		
Minimize the risk of obtaining lower profit ($)	16,280			0			20,432			938		
Maximize of the possibility of obtaining a higher profit ($)	152,834			130,172			156,980			142,586		

For example, in Table VI with Scenario I, equal weights (33%) are assigned to the pessimistic, most possible, and optimistic values. It is found that the overall satisfaction is 53.00%, and the outcomes of maximum most possible value of profit, minimum possibility of obtaining a lower profit, and maximum of the risk of obtaining a higher profit are $84,866, $16,280, and $152,834, respectively.

The best result of the PTM policy is from setting the weight of the most likely value at 80% and 10% at both pessimistic and optimistic values (Scenario III). Similar to the PTR policy, the profit generated from Scenario IV (the optimistic case) is lower than from Scenario III. This is because the manufacturing process cannot fulfill the optimistic demand. As a result, a lower revenue and a higher shortage cost incur.

As for a comparison between the two policies, it was found that the PTR policy can outperform the PTM policy in terms of profit in all objective functions. However, the profit of the PTR policy in Scenario II when it is likely to be a pessimistic condition is not much higher than the profit of the PTM policy. In fact, they are equal (at 0) when we try to minimize the risk of obtaining a lower profit. In addition, when the returned component ratio is further reduced to be lower than 60% (0.6), the profit of the PTM policy is shown to be even higher than the profit of the PTR policy. This is because the PTR policy cannot gain an advantage from using the returned components (which are cheaper) and needs to use more new components. This shows the vulnerability of the PTR policy in the case of future pessimistic and uncertain conditions. It is more subject to uncertainty and the instability of returned components.

TABLE VII
Result comparison

The PTR Policy		
Priority-To-Remanufacturing policy (PTR)	Linear Programming (LP) model	Possibilistic Linear Programming (PLP) model from Scenario III
Objective function λ	Max z	Max λ
(overall degree of satisfaction)	100%	54.08%
z (Profit)	$ 114,753.08	($45,801, $114,280, $182,668)
The PTM Policy		
Priority-To-Manufacturing policy (PTR)	Linear Programming (LP) model	Possibilistic Linear Programming (PLP) model from Scenario III
Objective function λ	Max z	Max λ
(overall degree of satisfaction)	100%	50.71%
z (Profit)	$ 111,849.05	($20,432, $88,882, $156,980)

Comparison between the deterministic and the best stochastic results

Table VII compares the results between the optimal LP result under a deterministic condition and the best PLP result under a more realistic stochastic condition. As seen in Table VII, the most likely profits that are generated from the uncertain circumstance are lower as compared to the profits under no uncertainty as the overall degree of satisfaction is lower. This is because the result was recommended from the scenario that yields the lowest degree of satisfaction among the three objectives, which are maximizing the most likely value of profit, minimizing the risk obtaining a lower profit, and maximizing the possibility of obtaining a higher profit. The PTR policy and the PTM policy under Scenario III show the best result among experimental scenarios, whereas The PTR policy generates a higher profit than the PTM policy in all cases. With the range of profit from each scenario obtained from PLP, decision makers are well prepared for any expected outcome. This is an important feature for decision makers to build the production planning and inventory control subject to an uncertain environment.

VI. Conclusions

Production planning and inventory control is intermediate planning for finding suitable levels of disposal units, production units, lost sales, inventory, and stock outs to meet uncertainty in the forecast demand and fluctuation of related operating costs, number of returned components, and machine productivity. This study finds the optimal inventory control policy of a hybrid manufacturing/remanufacturing system under two priority policies, Priority-To-Remanufacturing (PTR) and Priority-To-Manufacturing (PTM). Possibilistic linear programming is introduced to optimize and find the optimal result in this uncertain environment. It maximizes the most possible value of the imprecise profit, minimizes the risk of obtaining a lower profit, and maximize the possibility of obtaining a higher profit by pushing the three prominent points with the triangular distribution towards the right (as profit maximization). Results from this deterministic case show that the PTR policy is slightly better than the PTM policy. The results from the stochastic case also confirm that the PTR policy is better than the PTM policy in terms of having a higher most likely value of the profit in every scenario. However, the profit of the PTR policy when it is likely to be pessimistic is not much higher than the profit of the PTM policy. In fact, they are equal (at 0) when we try to minimize the risk of obtaining a lower profit. In addition, when the returned component ratio is further reduced to be lower than 60% (0.6), the profit of the PTM becomes higher than the profit of the PTR policy.

As in the case study, the proposed method can be used to solve real-world planning problems involving imprecise datas through an interactive decision-making process. The proposed method constitutes a systematic framework that helps the decision-making process, enabling a decision maker to interactively modify the imprecise data until a satisfactory solution is found. Notably, the optimal goal values using the LP approach are imprecise since the forecasted demand, related operating costs, and the number of returned components are always imprecise in nature. This brings the results closer to real-world problems. Decision makers should have some knowledge in advance to prepare and take necessary action for future uncertainty.

This study focuses on multi-periods with a single product from a hybrid manufacturing/remanufacturing problem. It also provides information on different policies in response to any designed variations. Additionally, the approach also considers the actual tradeoff between the PTM and the PTR policies in each circumstance. This lets us know how each policy would be beneficial or vulnerable depending on uncertain conditions.

The main limitation of our case study is the assumption of the triangular distribution that represents imprecise data. Decision makers should make use of and obtain appropriate distributions based on true judgment on past resources. Future researchers can also explore different levels of the relative importance of individual goals and different types of distributions, to make their models to be better suited to their practical applications.

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[35] J. K. Author, private communication, Abbrev. Month, year.
[36] J. K. Author, "Title of paper," unpublished.
[37] J. K. Author, "Title of paper," to be published.

Examples:

[38] A. Harrison, private communication, May 1995.
[39] B. Smith, "An approach to graphs of linear forms," unpublished.
[40] A. Brahms, "Representation error for real numbers in binary computer arithmetic," IEEE Computer Group Repository, Paper R-67-85.

Basic format for standards:

[41] *Title of Standard*, Standard number, date.

Examples:

[42] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.
[43] Letter Symbols for Quantities, ANSI Standard Y10.5-1968.



First A. Author and the other authors may include biographies at the end of regular papers. Biographies are often not included in conference-related papers. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year the degree was earned. The author's major field of study should be lower-cased.

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The third paragraph begins with the author's title and last name (e.g., Dr. Smith, Prof. Jones, Mr. Kajor, Ms. Hunter). List any memberships in professional societies. Finally, list any awards and work for committees and publications. If a photograph is provided, the biography will be indented around it. The photograph is placed at the top left of the biography, and should be of good quality, professional-looking, and black and white (see above example). Personal hobbies will be deleted from the biography. Following are two examples of an author's biography.



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Mr. Author's awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).

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