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Dear Colleagues,

It is recognized that engineering and technology are important tools in Thailand 4.0. Today, the technology is moving very fast that make the theory and truthful information in the text books does not often provide useful information for learning and use for citation. For this situation, we formally launched the International Scientific Journal of Engineering and Technology (ISJET) and proceed to issuing quality articles through rigorous and quick review processing schemes. This year, the ISJET is indexed in Thai Journal Citation Index (TCI) that can assure our journal quality.

As we forward-thinking, move ahead and build on our success, 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 us improve further the quality of our offering.

Finally, on behalf of the Editorial Board, I would like to take this opportunity to thank everyone who has contributed to the ISJET in various capacities, and to urge you to continue submit your valuable research to publish in the journal. Your cooperation will be highly appreciated. If you have any questions or suggestions, please directly email to me or journal coordinator. I look forward to hearing from you.

With kind regards,

Assoc. Prof. Dr. Parinya Sanguansat
Editor-in-chief
parinyasan@pim.ac.th

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สถาบันการจัดการปัญญาภิวัฒน์

Customer Retention of Using Mobile Banking a Case Study of One of the Largest Bank in Thailand

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Abstract—**This research is focused more on the customer retention of using mobile banking service in Thailand i.e. a case study of one of the largest bank in Thailand. The study has combined personality dimensions of Technology Readiness Index and cognitive dimensions of Technology Acceptance Model with antecedents such as consumer satisfaction and loyalty to provide robust framework of mobile banking adoption process. Also the study examines the influencing factors that determine the customer loyalty for ABC mobile banking application. The Inferential Analysis was done to test the validation of the technology readiness and acceptance model (TRAM) constructs and their interrelationship among each other. The finding reveals that TRAM variables have a significant influence on use of ABC Bank Mobile application in Bangkok. The study concludes with a discussion on practical implications of the research across similar service providers within the industry.**

Index Terms—**Mobile Banking, Technology Readiness Index (TRI), Technology Acceptance Model (TAM), External Factors, Customer Satisfaction, Reuse Intention**

I. Introduction

Mobile banking is defined as providing customers with the support and efficiency to bank from anywhere and anytime using a mobile device and a mobile service i.e. Text messaging (SMS) or via the use of banking application citation. Mobile banking removes space and time constants for banking activities for example, checking account balance, transferring money from one account to another etc. According to Mary, R. [1], Mobile banking was first introduced in the late 1990s in New York by the four major banks i.e. City Bank, Chase Manhattan Bank, Chemical Bank and Manufacturer Bank. In Thailand, despite of many people inclined towards the traditional banking system i.e. teller transaction, the mobile penetration is rising rapidly and now going digital is norm for almost every banking institution [2]. Most of the banks have their own application for smart phones through which the customers can easily do the online banking transaction anytime and anywhere. The penetration of Mobile Banking in Thailand is around 43% [3]. According to Master Card's Mobile Shopping Survey [4], it was found that 61.1% of Thai consumer use mobile phone to purchase goods and services and the figure shows that Thailand ranked fourth among fourteen Asia-Pacific market surveyed by Master Card. Research revealed that 397 million baht worth of value of transaction is done via mobile banking in Thailand as of June 2016. [5].

This research is focused more on the finding out the major factor affecting the customer intention for using mobile banking application and the determinants of customer loyalty for mobile banking application. Due to confidentiality, purposed company information in this research cannot be disclosed. Therefore, researcher names it as ABC Bank.

II. Literature Review

For many years, scholars have been investigating the factors which could influence the acceptance of new technologies. Among frameworks that have been developed, based on past studies, includes the Technology Acceptance Model, TAM [5, 6], Theory of Reasoned Action, TRA [7]. In the Theory of Reasoned Action, behavioral intention (BI) is placed as the only direct antecedent of actual behavior (AB). Also, it is assumed that BI can accurately predict AB if three boundary conditions that Fishbein and Ajzen [7] propose can be hold. These three conditions are: (1) the degree to which the measure of intention and the behavioral criterion correspond with respect to their levels of specificity of action, target, context, and timeframe, (2) the stability of intentions between time of measurement and performance of the behavior, and (3) the degree to which carrying out the intention is under the volitional control of the individual. According to the TRA, before performing a behavior, a person might deliberate about his or her action. Ajzen and Fishbein [8] also mention that a person will consider various variables and aspects of his or her action before choosing to perform or not perform a particular behavior. Therefore, Ajzen and

Fishbein [8] assume that most actions of social relevance are under volitional control and this theory puts a person's intention to perform or not perform a behavior as the immediate determinant of action. An integration of the two models, the technology readiness and acceptance model (TRAM), first presented by Lin et al. [9], TRAM represents the latest contribution to merge general personality dimensions of TRI with system specific dimensions of TAM. Thus, explaining how personality dimensions can influence the way people interact with, experience, and use new technology. Furthermore, TAM has been the prominent model for studying and predicting users' acceptance of technology. It involves two important beliefs or factors which are perceived usefulness (PU) and perceived ease of use (PEOU). Firstly, perceived usefulness (PU) refers to the degree to which a prospective user believes that using a certain system will benefit his or her job performance. It derives from the definition of the word "useful" as "capable of being used advantageously". In a company, employees are rewarded for good performance with raises, promotions, bonuses, and others [10, 11]. It can be explained that the system with high perceived usefulness is the one that a user believes it has a positive use-performance relationship. However, perceived ease of use (PEOU) is the degree to which a prospective user believes that he or she will be able to use a certain system effortlessly. It is related to the definition of the word "ease" which is "freedom from difficulty or great effort". As people have limited effort, they have to allocate it to perform different activities; therefore, they do not want to spend much effort to use a system or technology. For this reason, the system which is easy to use is more likely to be accepted by users than the complicated ones.

A. Research Objectives

The followings are the objective of the research study;

1. To investigate the factor which influence customer intention to use ABC Bank Mobile Application in Thailand using integrated Technology Readiness Index (TRI) and Technology Acceptance Model (TAM) along with behavioral responses such as satisfaction and loyalty.
2. To examine the influencing factor that determines the customer loyalty for mobile banking application.

III. Method

Non-probability sampling; precisely web-based, self-selected online surveys is used for the survey. In self-selected online survey, questionnaire links are sent to target population and respondents have choice regarding their inclusion as sample for the study [12]. To ensure the survey was participated by target group, firstly people are introduced about the research with short description in the questionnaire. In addition, they are instructed to proceed with questionnaires only if they have used ABC mobile banking services. The researcher chooses Bangkok to collect the total sample size of 410. The research hypothesis for this study is derived from the study of literature review and the conceptual framework. The explanation of factors and derived hypothesis are as follows:

A Explanation of the terms

Perceived usefulness is defined as the degree of probability to which it is believed that by using particular mechanism in work helps to increase the efficiency and job performance [13].

Perceived ease of use is defined as the gradation to which it is believed that using a particular mechanism helps to make the task free from effort [13].

Attitude towards behavior is explained in a way that, people perception and their reaction towards favoring for the particular behavior [8].

Intention is explained as the people enthusiasm and determination to utilize their potential to move towards the aim [13].

TAM stands for Technology Accepted Model; TAM model explains that the use of technology is determined by the willingness towards the specific performance [5, 6].

TRA stand for Theory of Reasoned Action; TRA model explains that the performances of social significance are under desire control and are thus expected from the intention [6,8].

External factors in this research is defined as influence of friends and family, Siam commercial bank staffs encouragement to use the banking application, technology savvy (efficiency of using technology), advertisement influence and web security factors which affects the customers intention to use mobile banking application.

1) External Factor and Perceived Usefulness

H1: External factor has a positive influence on perceived usefulness of ABC Mobile Application.

2) External Factor and Perceived Ease of Use

H2: External factor has positive influence on perceived ease of use of ABC Mobile Application.

3) Perceived Usefulness and Attitude towards ABC Bank mobile Application

H3: Perceived usefulness has a positive influence on attitude towards ABC Mobile Application.

4) Perceived Ease of Use and Attitude towards ABC Bank mobile Application

H4: Perceived ease of use has a positive influence on attitude towards ABC Mobile Application.

5) Perceived Usefulness and Intention to use ABC Bank mobile Application

H5: Perceived usefulness has a positive influence on intention to use ABC Mobile Application.

6) Perceived Ease of Use and Intention to use ABC Bank mobile Application

H6: Perceived ease of use has a positive influence on intention to use ABC Mobile Application.

7) Attitude towards ABC Bank mobile Application and Intention to use

H7: Attitude towards ABC Mobile Application has a positive influence on the intention to use it.

8) Intention to use and Reuse/loyalty

H8: Intention to use ABC Mobile Application has a positive influence on customer reuse intention of ABC Mobile Application.

B. Framework

The conceptual framework of this research appears below.

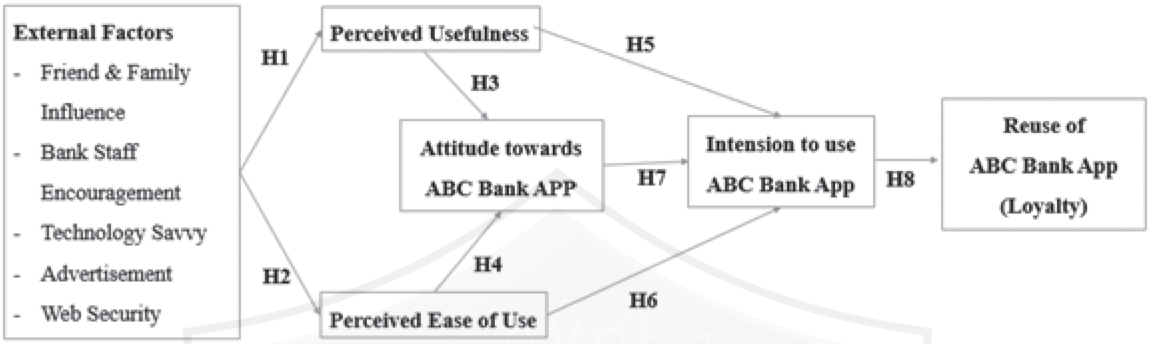

Fig. 1. Conceptual framework

C. Research Methodology

A simple descriptive analysis of quantitative data and a content analysis/logical analysis of qualitative data is applied in this research work. The questionnaires are analyzed using Microsoft Excel and Statistical packages. In the data analysis part of this study, the individual information was gathered and investigated with descriptive measurement. The dependability test led to assess the things of every variable. Different relapses were utilized to look at the hypothesized speculation. For this research, there were 450 questionnaires, out of which 40 questionnaire were rejected due to respondents' in-complete answer. The researcher collected 410 quality questionnaire out of 450 distributed to the sample group. The paper questionnaires were distributed by the researchers at the department store and universities nearby the ATM machines and Braches of ABC Bank. However, electronic questionnaires were distributed online via Google Form and sent to the respondents via email, line and other social mediums. Consequently, the respondents of electronic questionnaires were truly the internet users since they received and answered the research questionnaire online with no data loss.

IV. Results of the Study

TABLE I

Denigraphic Profile of Respondents

Characteristics Detail	No. of Respondents	Percentage
Gender		
Male	133	32%
Female	277	68%
Total	**410**	**100%**
Age		
< or equal to 20 years old	10	2%
21-30 years old	132	33%
31-40 years old	214	53%
41-50 years old	47	11%
> 50 years old	7	1%
Total	**410**	**100%**
Education		
Below Bachelor Degree	22	5%
Bachelor Degree	262	64%
Above Bachelor Degree	126	31%
Total	**410**	**100%**
Occupation		
Student	25	6%
Self Employed/Business	74	18%
Private Employee	276	67%
Government Officer	33	8%
House Wife	2	1%
Total	**410**	**100%**
Income (THB)		
Below 15,000	25	6%
15,001 – 30,000	130	32%
30,001 – 50,000	177	43%
50,000 & above	78	19%
Total	**410**	**100%**

Various statistical tools are used to analyze the data and test the hypothesis of the study. Descriptive statistical tools are used to present the demographic characteristics in terms of frequency and percentage and statistical tools like multiple regression, standard deviation and correlation analysis are used to analyze the other variables in the questionnaire survey. The summary on analysis of respondent demographic is shown in Table I.

The date interpretation result shows that the most dominating factor to influence the decision of adopting mobile banking is social influence i.e. form friends and families. Out of 410 respondents, 259 respondents i.e. 63.2% of the respondent believed that they started using ABC mobile banking application because their friends and families also use it. In addition, 341 respondents which comprises of 83.2% believes that if bank provides free internet service for those using ABC mobile banking application then they are more engaged to use the their mobile banking application. Furthermore, 279 respondents out of 410 respondents i.e. 68% of the respondents mostly use ABC mobile bank application because of its amount transfer features. Similarly, 53.2% of the respondents i.e. 218 respondents mostly uses ABC mobile banking application to pay bills and utilities.

TABLE II

Mean Value of Factors Towards Abs Mobile Banking Application

Factors	Mean Value	Standard Deviation	Mean Interpretation
External Factors	4.01	0.852	High Level
Perceived Usefulness	4.52	0.594	Very High Level
Perceived Ease of Use	3.99	0.703	High Level
Attitude	4.06	0.706	High Level
Behavior Intention	4.06	0.700	High Level
Loyalty	3.88	0.732	High Level

From the Table II it is clearly noticeable that the factor, perceived usefulness has a very high level of agreement as its mean value is 4.52 and the standard deviation is 0.594 whereas others factors like external factors has mean value of 4.01, perceived ease of use with mean value of 3.99, attitude and behavior intention with mean value of 4.06 and loyalty with mean value of 3.88 has high level of agreement. Therefore, it is considered that the all factors tested has at least high level of impact towards ABC Mobile Banking application.

TABLE III

Summary of Testing Hypotheses

N.	Hypothesis Path	β	t-value	p-value	R^2	Result
H_{1a}	External Factor (Friends & Family Influence) → Perceived Usefulness	0.022	0.391	0.696		No
H_{1b}	External Factor (Bank Staff Encouragement) → Perceived Usefulness	0.038	0.53	0.596		No
H_{1c}	External Factor (Technology Savvy) Perceived Usefulness →	0.148*	1.998	0.046	0.156	Yes
H_{1d}	External Factor (Advertisement) Perceived Usefulness →	0.172*	2.888	0.004		Yes
H_{1e}	External Factor (Web Security) Perceived Usefulness →	0.113	1.921	0.055		No
H_{2a}	External Factor (Friends & Family Influence) Perceived → Ease of Use	-0.012	-0.223	0.824		No
H_{2b}	External Factor (Bank Staff Encouragement) → Perceived Ease of Use	0.106	1.446	0.149		No
H_{2c}	External Factor (Technology Savvy) → Perceived Ease of Use	0.102	1.367	0.172	0.133	No
H_{2d}	External Factor (Advertisement) → Perceived Ease of Use	0.07	1.168	0.243		No
H_{2e}	External Factor (Web Security) → Perceived Ease of Use	0.179*	2.997	0.003		Yes
H_3	Perceived Usefulness Attitude →	0.221**	4.934	0.000	0.287	Yes
H_4	Perceived Ease of Use Attitude →	0.414**	9.228	0.000		Yes
H_5	Perceived Usefulness Intention →	0.241**	5.326	0.000		Yes
H_6	Perceived Ease of Use Intention →	0.243**	5.021	0.000	0.317	Yes
H_7	Attitude Intention →	0.239**	4.932	0.000		Yes
H_8	Intention Loyalty →	0.618**	15.882	0.000	0.382	Yes

*significant at 0.05, **significant at 0.01

Based on the finding of Table III, the results show that external factor influence on perceived usefulness of ABC Bank mobile application, only the two factors of external variable has the p-value less than 0.05 i.e. technology savvy with p-value of 0.046 and advertisement with p-value of 0.04. This means that only these two external factors i.e. technologically savvy and advertisement factor has more influence on perceived usefulness of ABC Bank mobile application. The result of regression analysis of external factor influence on perceived ease of use of ABC Bank application, the result shows that only one factors of external variable has the p-value less than 0.05 i.e. web security with p-value of 0.03. This means from all the other external factor only web security factor has more influence on perceived ease of use for ABC Bank mobile application. That regression test value for perceived usefulness is 4.934 and perceived ease of use is 9.228 and p-value for both factors is 0.00 i.e. less than level of significance 0.05. This means perceived usefulness and perceived ease of use has positive influence on consumer attitude towards the use of ABC Bank Mobile application. Also, the result shows that regression test value for perceived usefulness is 5.326, perceived ease of use is 5.021 and consumer attitude is 4.923. The p-value for all of them is 0.00 i.e. less than level of significance 0.05. This means perceived usefulness and perceived ease of use and consumer attitude has positive influence on consumer intention to use ABC Bank Mobile application. And finally, the result shows that regression test value for intention is 15.882 and p-value is 0.00 i.e. less than level of significance 0.05. This means Intention to use ABC Bank application has positive influence on consumer loyalty (reuse intention). The result of R Square had indicated that the variation of External Factors towards Perceived Usefulness is 0.156 which mean 15.6% of variation in Perceived Usefulness was influenced by External Factors. The other 84.4% remain uninfluenced. The variation of External Factor towards Perceived Ease of Use is 0.133 which mean 13.3% of Perceived Ease of Use was influenced by External Factors. The other 86.70% remain uninfluenced. The variation of Perceived Usefulness and Perceived Ease of Use towards Consumer Attitude is 0.287 which mean 28.7% of variation in Consumer Attitude was influenced by Perceived Usefulness and Perceived Ease of Use. The other 71.30% remain uninfluenced. The variation of Consumer Intention towards Loyalty (reuse intention) is 0.383 which mean 38.3% of variation in Loyalty (reuse intention) was influenced by Consumer Intention The other 61.70% remain uninfluenced.

V. Implication and Conclusion

The research result shows that the major influencing factors which affect the customer loyalty for using mobile telecommunication service are external factors like, friends and family influences, bank staff encouragement to use the mobile banking, technology savvy, media influence like advertisements and sense of web security. The other factors like, convenience, flexible and hassle free banking transaction and easiness to use the ABC Bank mobile application. All of these factors have a direct impact on the customer loyalty and the intention for using ABC Bank mobile application for a longer period of time. Also, the result shows that consumer reuse intention i.e. loyalty has a significant relationship with behavioral intention for service retention. The more the consumer is satisfied, the more reluctant they are in terms of ABC Bank mobile service switching behavior.

The research suggest that the number of ABC Bank Mobile users and compared to their current bank users is very small in number, so the bank should focus more on endorsing their services and sell on the value to attract more customers to adopt its mobile banking application. Awareness on the use of mobile banking service is essential in the initial stages of adaptation so one of the precaution that should be taken by ABC Bank is through advertisement and promotion.

Acknowledgment

My sincere thankfulness is extended to my advisor, the Dean and my all anonymous respondents that giving their valuable time for answering the questionnaires.

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Designing an Intermodal Transportation Network: A Case Study in Viet Nam

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***Abstract*—The ITND model developed in this study addresses the construction of the intermodal transportation network and finding the transportation routes for each commodity from the origin to destination. The objective function was to minimize the total cost, including the fixed transportation cost, the variable transportation cost, the emission cost, and the transfer cost. The model also included the node capacity constraints, the detour constraints, and the vehicle utilization constraints. The model was tested with data from the south of Viet Nam transportation network. Multiple experiments were conducted in order to observe the effect of each constraints and the characteristics of the model with different constraint sets. The results show that by including all constraints to the model, the resulting network perform better in terms of terminal capacity (and traffic), additional transportation distance (detour), and vehicle utilization, with the expense of increasing the total cost by 2.9%.**

***Index Terms*—Intermodal transportation, transportation network design, congestion, vehicle capacity utilization, detour factor**

I. Introduction

The globalization, the advancement in technology, and the overly increasing population have significantly accelerated the change in international trade and economy. The competition is very intense like never before, and the efficacy of the logistics management has now become a key factor affecting the economic development. One of the key performance indicators is the transportation cost that contributes largely for over 50% of the total logistics cost [1]; this makes it to be one of the major concerns of the industry. In order to reduce such expense, the transportation has to operate as optimal as possible and require a good transportation system to operate on. More specifically, the efficient transportation system allows the transportation to possibly be cheaper, faster, safer, more reliable, and less interruptions. However, achieving goal is very difficult, especially, when the multiple transportation modes co-operating on the same system are considered.

Different transportation modes are different in terms of service price, speed, reliability, accuracy, scheduling, convenience, and safety [2]. The detailed study for comparing different transportation modes with the effects of distance, shipping time, fuel cost, weight and value of commodity can be found in [3]. Among all modes, trucking is usually more expensive but it has many other competitive advantages (e.g. door-to-door shipment and short delivery time) [4]. Rail and water transportation are usually more efficient for carrying large, heavy, and high density load over long distances but those ways spend a lot of time. To this end, the intermodal transportation combines different transportation mode in order to overcome weaknesses and utilize the strength of each mode. Potential benefits of intermodal transportation include the opportunity to 1) *achieve efficient operation and economies of scale*, 2) *improve vehicle capacity utilization*, 3) *decrease congestion*, 4) *reduce emissions into the environment*, and 5) *create a safety and reliability system*. All these are efforts toward the ultimate goal to improve service quality and reduce the cost.

The cooperation in intermodal transportation requires shipments to transfer from one mode to another mode at intermodal terminals [5]. The transfer at these terminals, and the movement (of all transportation modes) between terminals can define the performance of the whole system. Therefore, the intermodal transportation network must be pre-determined for the intermodal transportation to operate on. The network must allow a synchronized movement and transfer, so as to achieve a good transportation system, which will eventually allow the transportation to possibly be cheaper, faster, safer, more reliable intermodal transportation.

II. Literature review

The discussions over the benefits of intermodal transportation have been widely found in literature review. The transportation of wood energy over the road was the most cost-competitive only when distance was short (60 km. or less) [6]. However, over longer distance, the combination of railway and roadway was more cost-effective. The similar result as reported for the comparison between the intermodal transportation with inland waterway and roadway transportation [7]. According to [8], combining roadway transportation to other modes can lower the transportation cost as much as 10-20%, especially when the distance is more than 200 km. Not only in terms of cost reduction, environmental friendliness was also another major benefit of intermodal transportation. In addition to cost reduction, the environmental friendliness was also focused as one of the major concerns. The CO_2 emission was reduced about 50% in the intermodal transportation comparing to truckload transportation, and the energy efficacy and noise were mentioned and analyzed for the same scope [9], [10].

There are many studies on the design of the intermodal network. An intermodal network design that locates intermodal terminal and selects the appropriate transportation route was described and introduced as an alternative direction for saving the operation costs and reducing emissions of transportation [11]. Limbourg et al. (2009) provided an iterative procedure to find the optimal locations of a given number of hubs [12]. Arnold et al. (2004) developed a model to select optimal location of rail/road terminals for freight transportation network [13]. Van Duin et al. (1998) presented the three-stage model to find the terminal location and the simulation for the design of intermodal transportation services [14]. Chang (2008) proposed a model to select the best transportation routes over the international intermodal network [15]. Mathematical models and solution methodologies for the intermodal transportation network design problem were found in [16-19]. Moreover, a generic framework for transport network design was presented and identified in [20]; the framework considered about *1) the design of transport systems, 2) direct link, 3) corridor, 4) hub-and-spoke, 5) connected hubs, 6) static routes, and 7) dynamic routes.*

In general, the transportation network design problem considered constructing the transportation network while minimizing the total of the facility cost and the transportation cost. The intermodal network problem normally includes the emission cost to the total cost. In this study, the intermodal network design problem [21] was extended to explicitly include three other factors, 1) facility capacity, 2) capacity utilization of vehicle, and 3) detour limitation. These three factors immensely affected the operational performance of the intermodal network but requirements for all the stakeholders of the transportation chain were ensured.

III. The intermodal transportation network design model

A. General problem description

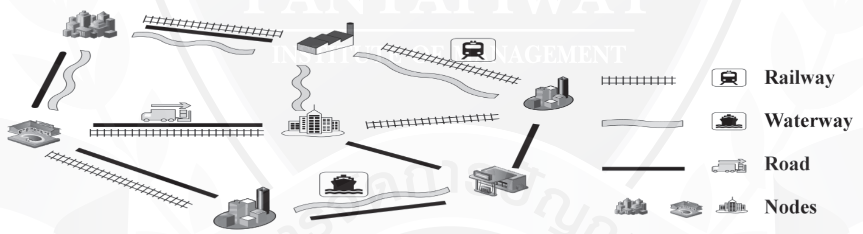

Fig. 1. Intermodal transportation network

The intermodal transportation network design model (ITND) in this study considers a large geographical area that consists of N nodes. These nodes are terminals (e.g. seaport, inland port, inland container depots, industrial park) that shipments can (but not necessary) change modes. They are connected by either roads, railways, or inland waterways as shown in Fig. 1. All connections are represented by arc A_{ij} (i, j $\in$ N). Moreover, there are K commodities, for some of the nodes are the origin O^k or the destination nodes D^k of a commodity k $\in$ K. The objective of the ITND model is to construct an intermodal transportation network by considering the arc A_{ij} to be used in the final network. The network should contain the routes for all commodities, from their origins to so that the transportation is efficient as possible. Therefore, the objective function composes of the transportation cost, both fixed and variable, the transfer cost, and the emission cost. The variable transportation cost includes the fuel costs, crew costs, and any other cost occur during the transportation. The fixed cost occurs when establishing transportation links, operating wages, handling (loading/unloading commodities on and off the vehicles). The transportation cost directly associates with the ability of the network whether it allows the carriers to operate efficiently or not. The transfer cost incurs at the intermodal node, where commodities are exchanged from one transportation mode to another. Modes exchange allows the carriers to utilize capacity of vehicles. For the emission cost, it is charged for a release of the greenhouse gas from the vehicles into the atmosphere. Vehicle with high capacity usually has lower emission cost.

B. Terminal Capacity and Congestion

The capacity of terminal facilities and traffic congestion are highly related to each other. Intermodal transfer and sorting/resorting activity (with or without the mode transfer) takes place at the terminal facility. If the terminal capacity is high enough, then the terminal can serve large amount of commodity in reasonable time. On the other hand, if the capacity is relatively low, then congestion is to be expected whenever the facilities are overly utilized. Specifically, traffic congestion is characterized by the sluggish speeds and long queue waiting, which can potentially cause delays in transportation. Limitation of equipment capacity can also create congestion within facilities. The overuse of terminal facilities and congestion have significantly impacted on the efficacy of the transportation network as a whole.

Capacity constraints were found in mathematical model. Rodriguez et al. (2007) proposed the method to find congestion cost in hubs [22]. They also proposed that the balance of flows in hubs can potentially improve travel times and, eventually, improve customer service efficiency. A hub-and-spoke network design model with traffic congestion was developed by Elhedhli et al. (2005) [23].

C. Detour Factor

In addition to the three indicators described above, there are other factors that transportation providers are normally fully aware of. One is the detour factor that can be defined as the ratio between the length of additional distance from origin to destination and the length of the shortest path for any commodity [24]. This additional distance is normally kept at minimum level due to its effect on the fuel cost, the driver's cost, and many more. However, it is not always the case that the additional distance can be avoided and the commodity can be transported directly from the origin to the destination. Especially in the ITND where commodities can change transportation mode, but only at the terminal facilities. Therefore, commodities must take a detour to terminal facility in order to change mode and achieve economy of scale. Some discussion about detour in transportation network can be found in the literature. Ballou et al. (2002) indicated that detour factor depend on network density, the number of terminal in network, and natural obstacles [25]. Jung et al. (2013) presented a heuristic algorithm to maximize the profit with subjected to limited detours [26]. In term of mathematical model, Üster et al. (2007) derived a network design model with a circuitry constraint and developed a heuristics method to solve the model [27]. Üster et al. (2011) extended the model to include load-imbalance constraints and developed a Benders decomposition algorithm to solve the model [28]. In comparison, their percentage circuitry constraint considered unimodal transportation, whereas, the detour constraint herein considered the weight average of multiple transportation modes and routes.

D. Capacity Utilization of Vehicles

Another factor affecting the intermodal transportation network design performance is the utilization of the vehicle. Maximizing vehicle utilization can help saving cost and reducing the delivery time [29]. However, maximizing capacity utilization of vehicles is not only very difficult, but also base on customer demands, characteristic of good, and schedule plan. The detailed studied on the vehicle capacity utilization in freight transportation was introduced and applied in various applications [30]. The utilization of vehicles has been considered in many studies for unimodal transportation. McKinnon et al. (2010) reported that there are many causes that affect the utilization of trucks capacity in transportation (e.g. the market, regulation, inter-function, infrastructure, and equipment) [31]. For waterborne transportation, Styhre (2009) examined vessel capacity utilization and analyzed strategies to enhance vessel capacity utilization [32]. Maraš et al. (2013) showed that the average utilization of the barge container equal to 88% is the level that maximize the profit of a shipping company [33]. Moreover, according to the Liner Service Providers in study [34], 50%-90% of the vessels capacity was used to ensure profit for carriers. In modeling aspect, Goetschalckx et al. (1989) established a mathematical model for minimizing the total truck travel distance with respect to truck capacity [35]. Kim et al. (2009) proposed an efficient vehicle route planning that minimize the trip distance with respect to vehicle capacity utilization constraint [36].

E. Sets and Parameters

N	Set of nodes in the region (1,…, n)
K	Set of commodities (1,…, k)
M	Set of transportation modes (1,…, m)
A	Set of arcs (i, j) (i,j Є N)
c_{ij}^{m}	Unit transportation costs on arc (i, j) Є A by mode m Є M ($ per ton-km)
f_{ij}^{m}	Unit fixed costs for transportation on arc (i, j) Є A by mode m Є M ($ per ton)
ω	Unit transfer costs ($ per ton)
p^{m}	Unit emission costs for mode $m \in M$ ($ per ton)
d_{ij}^{m}	Distance of arc $(i, j) \in A$ for mode $m \in M$ (km)
$S_{O^kD^k}$	The shortest path distance from node O(k) to node D(k) of commodity $k \in K$ (km)
b_i^k	The difference between the quantity of commodity $k \in K$ entering and leaving node $i \in N$ (ton)
h_i^k	The absolute value of b_i^k (ton)
u_{ij}^{m}	The vehicle maximum capacity when traveling on arc $(i,j) \in A$ by mode $m \in M$ (ton)
O^k	The origin of commodity $k \in K$
D^k	The destination of commodity $k \in K$

r^k The quantity of commodity $k \in K$ that is to be sent from O(k) to D(k) (ton)

φ The minimum utilization of vehicle capacity (percentage)

ε The detour factor

Vi The maximum capacity for node $i \in N$ (ton)

F. Decision Variables

x_{ij}^{km} Flow variable for commodity $k \in K$ on arc $(i, j) \in A$ by mode $m \in M$ (ton)

y_{ij}^{m} Number of vehicles transported on arc $(i, j) \in A$ by mode $m \in M$ (unit)

z_{i}^{km} The transferred quantity of commodity $k \in K$ by mode $m \in M$ at node $i \in N$

G. Mathematical Modelling

$$\text{Minimize} \quad \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} c_{ij}^{m} x_{ij}^{km} d_{ij}^{m} + \sum_{(i,j)\in A}\sum_{m\in M} f_{ij}^{m} y_{ij}^{m} + \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} p^{m} x_{ij}^{km} + \frac{1}{2}\omega \sum_{i\in N}\sum_{k\in K}\left(\sum_{m\in M} z_{i}^{km} - h_{i}^{k}\right) \tag{1}$$

subject to

$$\sum_{j\in N}\sum_{m\in M} x_{ij}^{km} - \sum_{j\in N}\sum_{m\in M} x_{ji}^{km} = b_{i}^{k} \qquad \forall i \in N, \forall k \in K \tag{2}$$

$$b_{i}^{k} = \begin{cases} r^{k} & i = O(k) \\ -r^{k} & i = D(k) \\ 0 & \text{otherwise} \end{cases} \quad \text{and} \quad h_{i}^{k} = \begin{cases} r^{k} & i = O(k) \;\; \text{or} \;\; i = D(k) \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$\sum_{k\in K} x_{ij}^{km} \le u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \tag{4}$$

$$\sum_{j\in N} x_{ij}^{km} - \sum_{j\in N} x_{ji}^{km} \le z_{i}^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \tag{5}$$

$$\sum_{j\in N} x_{ji}^{km} - \sum_{j\in N} x_{ij}^{km} \le z_{i}^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \tag{6}$$

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} \le V_{i} \qquad \forall i \in N \tag{7}$$

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \le V_{i} \qquad \forall i \in N \tag{8}$$

$$\frac{\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} x_{ij}^{km}}{r^{k}} \le \varepsilon S_{O^{k}D^{k}} \qquad \forall k \in K \tag{9}$$

$$\sum_{k\in K} x_{ij}^{km} \ge \varphi u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \tag{10}$$

$$x_{ij}^{km} \ge 0 \qquad \forall (i,j) \in A, \forall m \in M, \forall k \in K \tag{11}$$

$$y_{ij}^{m} \in \{0,1,2...\} \qquad \forall (i,j) \in A, \forall m \in M \tag{12}$$

$$z_{i}^{km} \ge 0 \qquad \forall i \in N, \forall m \in M, \forall k \in K \tag{13}$$

The ITND can be modeled using a linear mix integer programming formulation (1–13). The objective function (1) is the total costs of the variable transportation cost, the fixed transportation cost, the emission cost, and the transfer cost. Constraints (2) are the flow conservation constraints for each node and each commodity. Constraints (2) also indicate the origin and destination of each commodity. Constraints (3) define b_i^k and h_i^k that are the difference quantity for each commodity between coming out of and coming into a node. Constraints (4) ensure that the capacity of the vehicle is not over utilized. Constraints (5) and (6) define the transferred quantity of each commodity by each mode at every node. Constraints (7) and (8) are the terminal facility capacity constraints. They ensure that both the total incoming and outgoing commodity do not exceed the node capacity. If the permissible capacity is set to be lower than the maximum level, the buffer capacity can help avoid congestion and promote smooth operation. Constraints (9) is the detour constrains. The left hand side of constraints (9) defines the total network distance of a commodity, and the right hand side is a permissible distance for each commodity. The detour constraints (9) ensure that the total network distance is within the ε percent of the shortest possible distance (shortest path distance) over the network. Constraints (10) is the minimum vehicle utilization constraints. These constraints force the utilization of vehicle to be at least φ percent of the full vehicle capacity. Constraints (11) and (13) are non-negativity constraints for flows and transferred quantity. Constraints (12) is the integer requirements for the number of variables.

IV. Computational experiments

A. Input Data and Transportation Network

The intermodal model was tested with data from the South of Viet Nam transportation network that consisted mainly of inland waterway and road. The network consisted of 15 nodes, represented the major provinces in the South of Viet Nam. These provinces are randomly assigned to be the origin or the destination of 30 different important commodities to be transported forward and backward between the origins and destinations. The commodity quantities that were estimated following the study of World Bank [37]. All provinces are linked together by either road and/or inland waterway as shown in Fig. 2.

The data of existing transportation network in Vietnam used in this research was gathered from many sources especially the distance d_{ij}^m (i, j Є N). For the road network, the distance data was obtained from the report of the World Bank [37]. For the inland waterway transportation, the locations and distances between any pair of ports are compiled from 1) 45 main inland waterways routes (http://viwa.gov.vn), 2) inland waterways routes information in South of Vietnam (http://cangvudtndhcm.gov.vn), and 3) the study of the World Bank [37]. The river-road distance between any origin-destination ports are calculated using Dijkstra's algorithm to find the length of the shortest path distance. The Dijkstra's algorithm creates a tree of shortest paths from the starting origin node, to all other nodes in the graph. The algorithm was coded in C++.

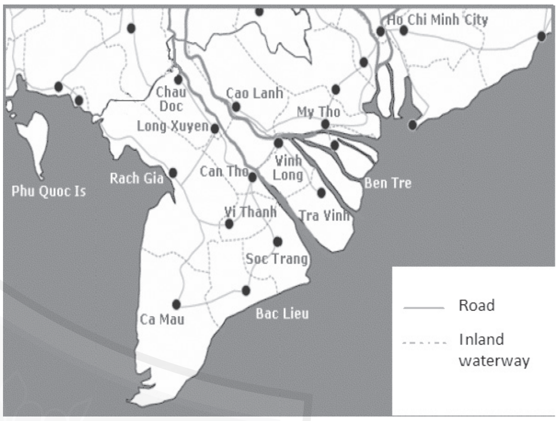

Fig. 2. The South of Viet Nam transportation network

B. Vehicle Capacity Estimation

The road infrastructure in the South of Viet Nam commonly has tonnage allowance limited to 20 tons per truck [37]. In terms of ship tonnage allowance, the calculation is based on the data provided in Table I. In Table I, column 1, 2 and 3 are the information for the classes of ship. Column 2 is the tonnage allowance of ship and column 3 is the equivalent number of full truckload. Column 4 (and 5) and 6 (and 7) are the information of the capacity in year 2005 and 2010, respectively. The number of ships in each class (column 5 and 7) can be calculated by dividing the values in column 4 (or 6) with the values in column 2. Column 8 is the ratio between the number of ships in year 2010 and year 2005. This ratio represents the growth of the popularity of each ship class within 5 years' time period.

For the number of ships, it is clear that smaller ships are very popular as the ship class "5-15" and "15-50" outnumber the bigger ship class. The number of ship class 5-500 DWT is very large but the capacity share is only 49% in 2010. In terms of the growth rate, it is also clear that ship class 700 and bigger are becoming more popular. The growth from 2005-2010 is 5.49 times for class "700-1000" and 20.47 times for class ">1,000". Thus the extend of the vessel fleet with regard to the larger capacity is the tendency in the future. On the other hand, economy of scale is the cost advantages that carriers obtain due to used big ship. Small ship is unable to achieve economy of scale which is essential in intermodal transportation. Therefore, we do not consider these small ships. By following this trend and considering the opportunity to aggregate many truckloads into large ship, we estimate the ship capacity to be 1000 tons.

TABLE I
DWT CARRYING CAPACITY OF RIVER VESSELS BY SIZE CLASS IN VIETNAM

Ship class (tonne)	Capacity per ship	Capacity in truckload	Total capacity in 2005	Number of ship in 2005	Total capacity in 2010	Number of ship in 2010	Growth 2005-2010
5-15	7.5	0.4	205,133	27,351	399,293	53,239	1.95
15-50	32.5	1.6	440,668	13,559	776,815	23,902	1.76
50-200	125	6.3	710,375	5,683	1,158,250	9,266	1.63
200-300	250	12.5	200,500	802	312,000	1,248	1.56
300-500	400	20	423,600	1,059	1,195,600	2,989	2.82
500-700	600	30	346,800	578	967,800	1,613	2.79
700-1000	850	42.5	254,150	299	1,394,850	1,641	5.49
>1,000	1,300	65	78,000	60	1,596,400	1,228	20.47

C. Cost element estimation

The unit transportation cost in this study consisted of the fixed and variable transportation cost. The unit fixed transportation cost is estimated based on 1) the unit loading/unloading commodities on and off per vehicle and 2) the unit operating wages cost per vehicle. The unit loading/unloading was estimated to be $2 per ton based on the fleet operational data from "VITRANSS-2" and an in-country interviews with inland waterway officers [37]. The unit operating wages cost were reported in "Circular No. 261/2016/TT-BTC" of Ministry of Finance (include maritime fees and charges). On the other hand, the variable transportation cost includes the fuel costs, crew costs, and any other cost occur during the transportation following the data used in [38]. As for the unit cost of variable transportation, we use the aforementioned value of $0.1 per ton by truck and $0.028 per ton by ship [38].

For the emission cost, the unit cost was obtained from the "Vietnam's government ratified Paris Agreement". This agreement was an act towards the carbon mitigation goals to help preventing the climate change. To achieve the commitments of the agreement, many countries applied emission trading systems and carbon taxes. Based on the Economic and Social Commission for Asia and the Pacific, the carbon taxes is $10 per ton of CO_2 emission. In addition, the amount of CO_2 emissions per ton-mile from truck and ship are obtained from the study of the World Bank [37]. Using the data from both sources, the unit emission cost used in this research is $0.0005654 per ton for truck and $0.000444 per ton for ship.

D. The Set-up of Computational Experiment

Twenty-four test instances were created with different unit fixed cost for truck and unit fixed cost for ship. All computational experiments were run on computer with Intel Core i7 2.6GHz and 8GB RAM. The ITND model was solved by CPLEX with C++ and Concert Technology (ILOG, Inc.) The study was phased by adding each type of constraints, one at a time, in order to observe their effects. The base model is the model (1-6) and (11-13). Model 1 is the base model with the terminal capacity constraints (7) and (8). Model 2 is Model 1 with the detour constraints (9). Model 3 is Model 2 with the vehicle utilization constraints. Fig. 3 summarized the step-by-step development of these models, from the base model to model 3.

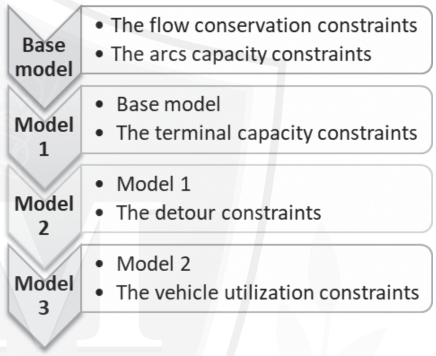

Fig. 3. Model development

E. Computational Result

1) Experiment 1

The effect of the capacity constraints can be observed by comparing the base model with model 1 and the result is shown in Table II. The first 3 columns provide the information of the node (terminal locations). Column 4-5 and 6-7 are the total inbound – outbound traffic for the base model and model 1. It can be seen that the traffic is lowered with the inclusion of capacity constraints especially for node 7 and 12 where the incoming traffic is relatively close to the capacity. The inbound traffic level exceeding the capacity at node 7 indicates a regular congestion. For node 12, the inbound traffic is higher than 90% of the capacity indicates that congestion is very likely to occur especially with the fluctuation of traffic during the day during busy hours. With the inclusion of capacity constraints, the traffic now below the capacity for terminal node 7 and below 90% the capacity for node 12. The high traffic in node 12 indicate that the terminal will still be heavily used despite the limited capacity. Therefore, the result suggested the facility upgrade at node 12 to increase the capacity. As an alternative, the capacity parameter V_i should be lowered so that the model would direct some commodities entering node 12 to other nodes and leaving more capacity buffer at node 12.

TABLE II

THE CALCULATED INCOMING AND OUTGOING TRAFFIC OF THE BASE MODEL AND MODEL 1

Node	Name	Capacity (Tonne)	Base Model		Model 1	
			Incoming	Outgoing	Incoming	Outgoing
1	Binh Duong	10,000	118	719	118	719
2	Dong Nai	13,000	2,881	1,495	2,844	1,458
3	Vung Tau	10,000	387	840	455	908
4	Ho Chi Minh	24,000	4,339	5,904	4,380	5,945
5	Long An	16,000	915	2,613	1,052	2,750
6	Tien Giang	3,500	403	1,633	419	1,649
7	Ben Tre	2,000	2,009	483	1,974	448
8	Tra Vinh	1,500	138	-	138	-
9	Vinh Long	3,000	1,377	1,692	1,340	1,655
10	Dong Thap	3,000	213	2,940	213	2,940
11	An Giang/Kien Giang	5,000	3,381	1,491	3,374	1,484
12	Can Tho	4,500	4,179	1,171	3,985	977
13	Hau Giang	2,000	1,646	116	1,646	116
14	Soc Trang	4,000	673	1,284	673	1,284
15	Bac Lieu/ Ca Mau	4,000	116	394	116	394

2) Experiment 2

In order to see the impact of the detour constraint, model 1 and 2 were tested with 24 test instances. The results were shown in Table III.

TABLE III

THE CALCULATED DETOUR OF MODEL 1 AND 2

Instance	Model 1		Model 2	
	Average	Max	Average	Max
1	1.53	6.91	1.27	1.50
2	1.52	6.91	1.24	1.50
3	1.47	6.91	1.22	1.50
4	1.46	6.91	1.21	1.45
5	1.51	2.99	1.27	1.50
6	1.52	6.91	1.24	1.50
7	1.49	6.91	1.23	1.50
8	1.12	1.42	1.21	1.45
9	1.51	2.99	1.27	1.50
10	1.52	6.91	1.24	1.50
11	1.47	6.91	1.24	1.50
12	1.44	6.91	1.21	1.45
13	1.51	2.99	1.27	1.50
14	1.52	6.91	1.24	1.50
15	1.47	6.91	1.24	1.50
16	1.44	6.91	1.18	1.43
17	1.51	2.99	1.27	1.50
18	1.52	6.91	1.24	1.50
19	1.47	6.91	1.24	1.50
20	1.42	6.91	1.18	1.43
21	1.51	2.99	1.27	1.50
22	1.52	6.91	1.24	1.50
23	1.47	6.91	1.24	1.50
24	1.42	6.91	1.18	1.43
Average	1.47	5.87	1.23	1.48

Column 1 is the number of test instance. Column 2 (and 4) and 3 (and 5) are the average and the maximum of the calculated detour. Without the detour constraints, the average detour ranges from 1.12 to 1.53 with an average of 1.47. The maximum detour in most instances are either 2.99 or 6.91. These values indicate that the majority of the commodities encounter about 50% of additional distance and the detour can be as high as 5.91 in the worst case. On the other hand, with the inclusion of the detour constraints, the average and the maximum detour are significantly lowered. The calculated detours are now within 1.27 and 1.50 indicating that the detour is kept lower than 27% on average and no more than 50% in the worst case.

3) Experiment 3

The impact of vehicle utilization constraints is shown in Table IV by comparing the results from model 2 and 3. Column 1 is the vehicle utilization level and column 2 to 5 columns are the number of vehicles with their respective utilization. It is clear that the constraints forced the utilization level of both truck and ship to be higher and more practical. Without the constraints, the utilization can be as low as 20-40% for truck and ship which are not practical for the transportation providers. With the constraints, the utilization is then forced to be at least 50%, indicating that vehicle are planned and used more efficiently.

TABLE IV
THE CALCULATED VEHICLE UTILIZATION
IN THE MODEL 2 AND 3

Utilization	Model 2		Model 3	
	Truck	Ship	Truck	Ship
0-10%	0	0	0	0
10-20%	0	0	0	0
20-30%	0	1	0	0
30-40%	1	2	0	0
40-50%	1	3	0	0
50-60%	2	4	3	3
60-70%	2	5	4	4
70-80%	3	8	5	7
80-90%	4	9	7	8
90-100%	23	15	28	14

4) Experiment 4

In order to better seeing the characteristic of each model, the detailed cost components of the objective function and the calculated detour and vehicle utilization are compared in Table V.

In Table V, the total cost and the variable cost are at the lowest in the base model, whereas it is at the highest in the vehicle utilization model. This is due to the fact that the objective function (total cost) is more inferior when the model became more constraints. However, it can be seen that the largest total cost in Model 3 is only 2.9% more expensive than the smallest total cost in the base model. Therefore, the model can better control the construction of the network and the transportation without trading off too much of the total cost.

TABLE V
COMPARING THE RESULT FROM DIFFERENCE MODELS

	Base model	Model 1	Model 2	Model 3
Objective ($)	285,050	285,176	290,132	293,280
Variable cost ($)	117,666	117,899	118,936	122,823
Fixed cost ($)	164,343	164,265	168,177	167,065
Emission cost ($)	1,604	1,610	1,557	1,571
Transfer cost ($)	1,437	1,401	1,462	1,821
Minimum detour (unit)	1	1	1	1
Maximum detour (unit)	5.93	6.91	1.48	1.50
Average detour (unit)	1.48	1.52	1.23	1.26
Minimum truck utilization (%)	57	60	43	57
Maximum truck utilization (%)	100	100	100	100
Average truck utilization (%)	96	96	93	91
Number of truck (unit)	161	159	226	247
Total flows by truck (ton)	3,148	3,118	4,425	4,803
Minimum ship utilization (%)	38	37	35	54
Maximum ship utilization (%)	100	100	100	100
Average ship utilization (%)	81	81	78	82
Number of ship (unit)	24	24	22	21
Total flows by ship (ton)	19,633	19,747	17,982	17,940

The effects on the variable cost can be observed as follow: 1) the node capacity constraints forced the vehicle to travel in a less directed route in order to lower the capacity usage, 2) the detour constraints forced the transportation to be more directed, but it might come at the cost of using a more expensive vehicle, and 3) the vehicle utilizations forced the consolidation of load onto less number of vehicle, which then cause the load to be transported in a less directed direction.

The fixed cost, on the other hand, is lower in Model 1 (with the node capacity constraints), but at the highest in Model 2 (with the detour constraints). The capacity constraints caused the commodities to be transported in multiple routes in order to avoid overload at some nodes. This increase the possibility of consolidating multiple commodities onto one route and reduce the number of vehicles. The detour constraints have the opposite effect as they force commodities to be transported in a more directed direction which can be different between commodities, and then directly increase the number of vehicles.

The emission cost is lower with the Model 2 (with detour constraints) because when the commodities is transported in a shorter route, the emission is directly reduced. In Model 2 (with node capacity constraint), the emission cost is higher which due to the fact that commodities have to travel longer to more varieties of nodes just to reduce some the node capacity utilization.

In terms of the transfer cost, it is at the lowest in Model 1 (with node capacity constraints) as the commodities are disperse over multiple nodes which reduce the chance of consolidation onto the same vehicles, and to ships. The highest transfer cost is in Model 3 (with vehicle utilization constraints) as the constraints increase the amount of load on ships, if used, and increase the transfer.

In addition to the cost terms, the detour and the utilization level are also presented in Table V. The minimum detours are all the same and equal to 1 (same as the shortest path). The maximum detour and the average detour are lowered for Model 2 (with detour constraints) and the Model 3 (with vehicle utilization constraints) because they have the detour constraints included. For information on vehicle utilization, every model uses more trucks than ship (truck to ship ratio greater than 7). Both truck and ship utilization are lowered in the Model 2 (with detour constraints). This results from the attempt to reduce the additional travelling distance which indirectly require more vehicles and, eventually, reduce the utilization. The average truck (and ship) utilization and the number of trucks (and ships) have the reverse relationship. The more the number of vehicles, the smaller the average commodities per vehicle. The average truck utilization is the smallest, and the number of trucks used is largest in Model 3 (with vehicle utilization). This is because the vehicle utilization constraints were applied to both truck and ship. Some commodities that were normally transported by truck now change to ship in order to increase the lower ship utilization. The average ship utilization is the lowest in the Model 2 (with detour constraints). Hence, although ship transportation is efficient and economical, but it comes at the cost of additional distance. Therefore, to reduce the additional distance, the model ends up using much more trucks instead of ships.

V. Conclusion

Based on the results presented above, it can be seen that the intermodal transportation network can be more realistic with the inclusion of the node capacity constraints, the detour constraints, and the vehicle utilization constraints. Without these constraints, the resulting network may have some terminal that is overly used (encounter heavy traffic and congestion). Commodities may have to travel much longer than normal and cause delay in deliveries (large detour level). Vehicle may not be utilized efficiently (low utilization level) and not cost effective. By including all of constraints (node capacity, the detour, and the vehicle utilization constraints) all these limitations can now be better controlled with the expense of increasing the total cost by only 2.9%.

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Economic Dispatch Management of Electric Power Plants for Profit Maximisation

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***Abstract*—This paper presents a spreadsheet-based optimization program that was developed to help make a management decision on how much electricity and steam should be generated by each of the dual power plants and sold to each group of the customer during peak hours and off-peak hours to achieve the maximum profit without violating their sales contractual agreements. Several quantitative determination processes of unit cost, prices and profits were constructed to help understand the calculation procedure hierarchically and embedded into the program. The mathematical linear programming models for optimizing the total profit during both periods of time of use were formulated. Two feasible scenarios for each period of peak hours and off-peak hours towards profit maximization attainment were simulated. The simulation results show that the optimal scenario between the two is applicable to be executed in both periods of time of use. Although some electricity demand could not be fully satisfied and the company had to be penalized financially, this scenario provided the total maximum profit and was able to satisfy the power systems and the legal constraints and not severely violate the sales contractual agreements relative to another scenario. The results from sensitivity analysis show strong effects on the profitability allowing to examine a series of possible changes that will not affect the optimal solution of economic dispatch management.**

***Index Terms*—Economic dispatch, operations management, power plant optimization, linear programming, Excel solver, profit maximization**

I. Introduction

The key business strategy of the power plant business in the deregulated electricity supply industry (ESI) is to maintain profitability. National Power Supply (NPS) is the private cogenerated-power company that sells debentures to the general public to raise funds for business expansion. The right strategic move is to maximize profit from selling electricity and steam, at the same time funding the intensive research and development program to seek for new alternative energy in order to supplant limited fuels and lower cost of production.

The corporate annual report showed that electricity and steam is the major source of revenue ranging from 75% to 90%, but both revenue and profit have declined for the past five years. Decreased profit was partly due to monopolized pricing determination and volatile macroeconomic factors. The executives identified that the decreased profit is caused by independent management without applications of economic dispatch (ED) among the power plants, resulting in excessively stocking up the fuels, scheduling unplanned maintenance from machine breakdown and not being able to deliver some outputs to the customer.

The focus of this researchb022+ 4567890-53[]\ 5p+/7 study is on an ED management with two com wparative scenarios of optimal solutions towards profit maximization. The study aims to develop an optimization program for strategically managing ED of electricity and steam for the dual power plants to ultimately achieve the maximum profit. Sensitivity analysis was also performed to investigate the effects of cost-price-related factors on profitability allowing to foresee a series of possible changes that will not affect the best ED management solution.

A. Literature Review

According to the U.S. Energy Policy Act of 2005 [1], economic dispatch is defined as "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limit of generation and transmission facilities". The key underlying objective of ED problem solving is to determine the optimal point of generation units with minimum cost while satisfying load demands and system constraints [2].

Towards the end of the year 2016, a number of research papers in the field of ED have been published in many reputable sources. It seems that the entire set of recent studies intended to achieve this objective, but some of which [3-11] chose to minimize fuel cost instead of total cost of generation [12-19]. The rationale behind this might be because the fuel cost almost covers the total cost of generation. There is only one paper by [20] aiming to solve the ED problem for profit maximization; however, their constraints in the power system are generally indifferent to those found in common ED problems.

Two different power plant systems have been interested in the recent studies: the power only and the combined heat and power (CHP) systems. Apparently, most of the work devoted to solving ED problems in the plant system with power generating units, conversely only a few [14], [15], and [20] chose to solve ED problems in CHP system where both electricity and steam can be produced at the same time.

Considering solution methods applied, they are very diverse from simple methods to sophisticated ones since the authors modified or improved those particular methods to fit their ED problem characteristics or to improve the accuracy of computational results. For examples, [10] and [15] modified regular particle swarm optimization (PSO) method of [3] and [4] improved differential evolutionary (DE) of [12]. Alternatively, some authors innovatively developed solution methods; for instances, [6] developed a cuckoo search (CS) algorithm, and [13] developed an artificial immune system (AIS) algorithm. While the same solution method was used more than once but in different plant systems. For example, the AIS algorithm was first used by [13] in a conventional plant system and later used by [14] in a CHP plant system.

This study fills the research gap by extending the application of ED for profit maximization in a group of CHP/cogeneration power plants and considering local constraints in terms of system, demand-supply balances and contractual agreements. Briefly, the summary of the recent publications (2008-2016) about ED and the gap of this research study is demonstrated in Table I.

TABLE I
Summary Of The Recent Publications On Economic Dispatch.

Authors	Year	Objective	Plant System	Profit Max	Solution Methods
Balamurugan & Subramanian	2008	Minimum generation cost	Power	No	Differential evolutionary algorithm
Mahor	2009	Minimum fuel cost	Power	No	Particle swarm optimization
Behera	2011	Minimum generation cost	Power	No	Artificial immune system algorithm
Mahdad & Srairi	2011	Minimum fuel cost	Power	No	Improved parallel differential evolution
Basu	2012	Minimum generation cost	CHP	No	Artificial immune system algorithm
Dike	2013	Minimum fuel cost	Power	No	Modified lambda-iteration
Mohammadi-Ivatloo	2013	Minimum generation cost	CHP	No	Particle swarm optimization with time varying acceleration coefficients
Naama	2013	Minimum generation cost	Power	No	Tabu search algorithm
Sashirekha	2013	Minimum generation cost	CHP	No	Lagrangian relaxation
Serapião	2013	Minimum fuel cost	Power	No	Cuckoo search algorithm
Ashfaq & Khan	2014	Minimum fuel cost	Power	No	Modified linear programming
Rahli	2015	Minimum generation cost	Power	No	Variable weights linear programming
Tsai [1]	2015	Maximum profit	CHP	Yes	Improved genetic algorithm
Al-Shetwi & Alomoush	2016	Minimum fuel cost	Power	No	Genetic algorithm
Hansen & Mladenovic	2016	Minimum generation cost	Power	No	Dynamic programming
Srikanth	2016	Minimum fuel cost	Power	No	Genetic algorithm
Vignesh	2016	Minimum fuel cost	Power	No	Quantum particle swarm optimization
Zaman	2016	Minimum fuel cost	Power	No	Differential evolutionary algorithm
This research study	2017	Maximum profit	CHP	Yes	Linear programming

Remark: [1] Operational and system constraints are holistic and indifferent to typical ED problems.

II. Quantitative Determination For Costs, Prices And Profits Of Electricity And Steam

A. Unit Cost of Production

To estimate the cost per unit of electricity and steam generated, the data about coal, biomass, demineralized water, sand, chemicals, ash disposal, lime, sea freight and land freight is required. Variable cost, including fuels and consumable raw materials, is assumed to cover all of the unit cost. The components of the total unit cost and the estimation process flowchart can be shown in Eq. (1) and Fig. 1, respectively.

Total Unit Cost = Total Fuel Cost + Total Consumable Raw Material Cost (1)

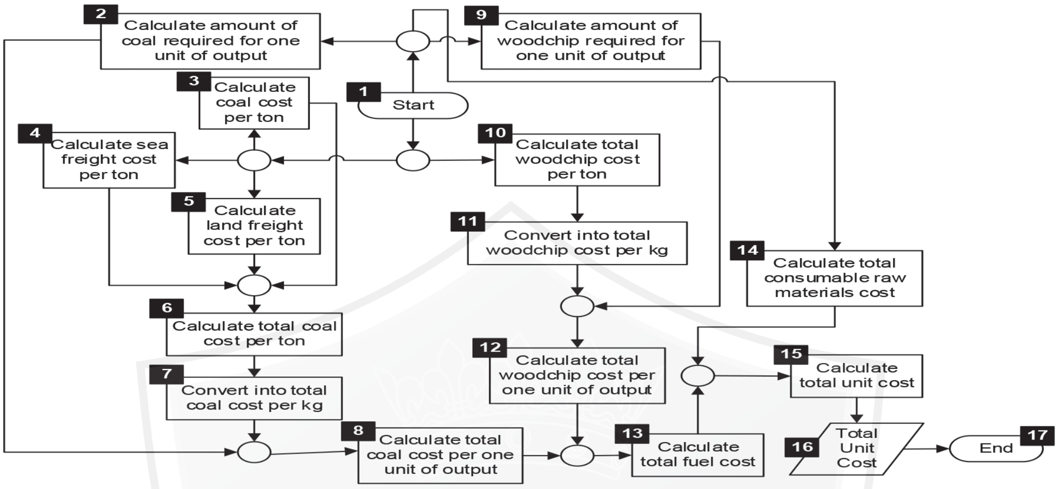


Fig. 1. Estimation process flowchart for the total unit cost of production

B. Unit Prices

The unit prices can be separately estimated for different products (electricity and steam), different groups of customers (EGAT, AA and Industry) and different times of use (peak hours and off-peak hours). For instances, estimating the electricity price sold to EGAT during peak hours should follow the estimation process flowchart illustrated in Fig. 2, on the other hand, estimating the electricity price sold to EGAT during off-peak should follow the estimation process flowchart illustrated in Fig. 3.

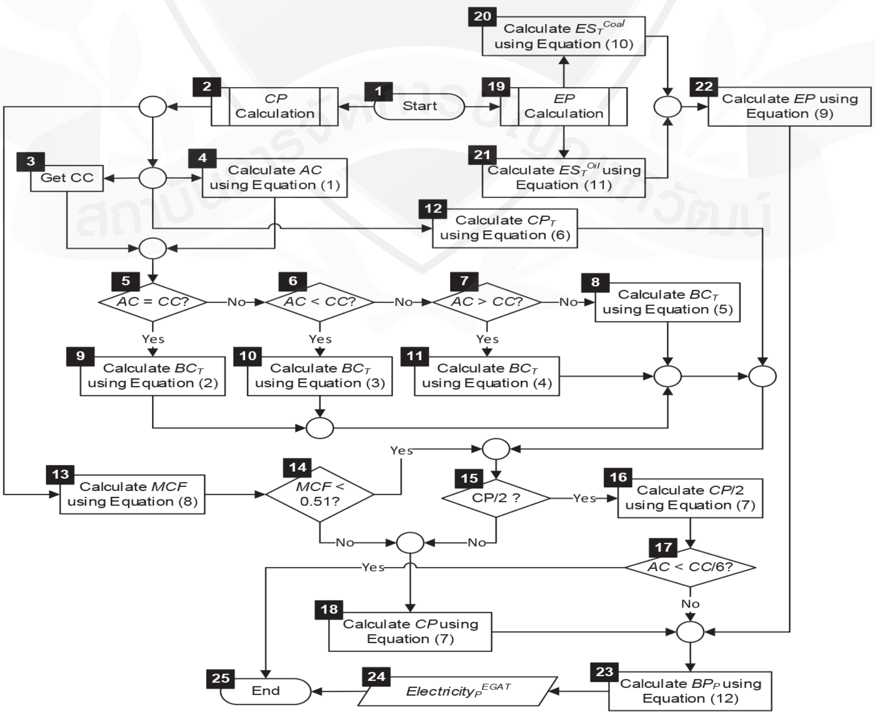


Fig. 2. Estimation process flowchart for selling price to EGAT during peak hours

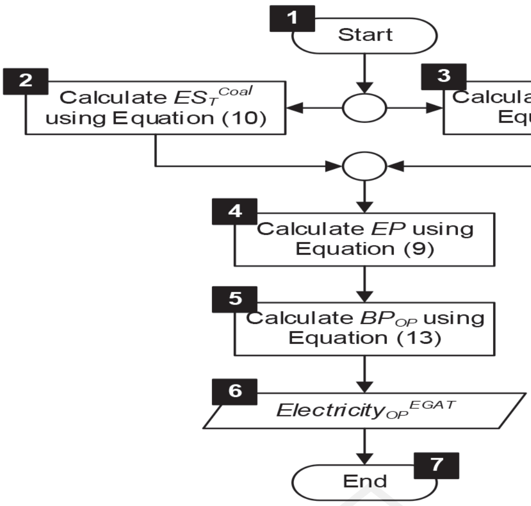


Fig. 3. Estimation process flowchart for selling price to EGAT during off-peak hours

C. Unit Profits

Profits can be calculated by directly subtracting the cost from selling price. However, they must be individually calculated due to different electrical products, different groups of customers and different times of use. For example, the electricity profit gained from EGAT during peak hours can be estimated by subtracting the unit cost of production from the selling price to EGAT during peak hours.

III. Spreadsheet-Based Economic Load Dispatch Program For Profit Maximization

A. Conceptual Design

1. Functionality

The developed program was given a name *NPS Economic Dispatcher* and must be embedded with a computation algorithm that is applicable to manage ED of the dual power plants by generating the optimal ED solutions under several restrictions with the maximum profit to the company.

2. Usability

NPS Economic Dispatcher must have a user-friendly human-software interface that requires only minimum knowledge in computer operation and application platform of users. They should not be required to understand the computation algorithm and the data entry procedure should be simple without spending excessive physical and mental efforts.

3. Validity

NPS Economic Dispatcher must provide valid solutions to the production planners that assists them in making decisions about ED management. After developing the program, the optimal solutions given by the program should be consistent with actual practices.

B. Formulation of Linear Optimization Model

1) Decision Variables

Let $X_{EGAT,A}^{Electricity}$ = Number of electricity units produced and sold to EGAT by Plant A

$X_{EGAT,B}^{Electricity}$ = Number of electricity units produced and sold to EGAT by Plant B

$X_{AA,A}^{Electricity}$ = Number of electricity units produced and sold to AA by Plant A

$X_{AA,B}^{Electricity}$ = Number of electricity units produced and sold to AA by Plant B

$X_{Industry,A}^{Electricity}$ = Number of electricity units produced and sold to Industry by Plant A

$X_{Industry,B}^{Electricity}$ = Number of electricity units produced and sold to Industry by Plant B

$X_{AA,A}^{LPSteam}$ = Number of LP steam units produced and sold to AA by Plant A

$X_{AA,B}^{LPSteam}$ = Number of LP steam units produced and sold to AA by Plant B

$X_{AA,A}^{MPSteam}$ = Number of MP steam units produced and sold to AA by Plant A

$X_{AA,B}^{MPSteam}$ = Number of MP steam units produced and sold to AA by Plant B

2) Objective Functions

a) Maximize the Profit during Peak Hours

$$\text{Maximise} \quad P_{EGAT,P}^{Electricity} X_{EGAT,A}^{Electricity} + P_{EGAT,P}^{Electricity} X_{EGAT,B}^{Electricity} + P_{AA,P}^{Electricity} X_{AA,A}^{Electricity} + P_{AA,P}^{Electricity} X_{AA,B}^{Electricity} + P_{Industry,P}^{Electricity} X_{Industry,A}^{Electricity} + P_{Industry,P}^{Electricity} X_{Industry,B}^{Electricity} + P_{AA,P}^{LPSteam} X_{AA,A}^{LPSteam} + P_{AA,P}^{LPSteam} X_{AA,B}^{LPSteam} + P_{AA,P}^{MPSteam} X_{AA,A}^{MPSteam} + P_{AA,P}^{MPSteam} X_{AA,B}^{MPSteam} \quad (2)$$

where $P_{EGAT,P}^{Electricity}$ = Profit per unit from selling electricity to EGAT during peak hours

$P_{AA,P}^{Electricity}$ = Profit per unit from selling electricity to AA during peak hours

$P_{Industry,P}^{Electricity}$ = Profit per unit from selling electricity to Industry during peak hours

$P_{AA,P}^{LPSteam}$ = Profit per unit from selling LP steam to AA during peak hours

$P_{AA,P}^{MPSteam}$ = Profit per unit from selling MP steam to AA during peak hours

b) Maximize the Profit during Off-Peak Hours

$$\text{Maximize} \quad P_{EGAT,OP}^{Electricity} X_{EGAT,A}^{Electricity} + P_{EGAT,OP}^{Electricity} X_{EGAT,B}^{Electricity} + P_{AA,OP}^{Electricity} X_{AA,A}^{Electricity} + P_{AA,OP}^{Electricity} X_{AA,B}^{Electricity} + P_{Industry,OP}^{Electricity} X_{Industry,A}^{Electricity} + P_{Industry,OP}^{Electricity} X_{Industry,B}^{Electricity} + P_{AA,OP}^{LPSteam} X_{AA,A}^{LPSteam} + P_{AA,OP}^{LPSteam} X_{AA,B}^{LPSteam} + P_{AA,OP}^{MPSteam} X_{AA,A}^{MPSteam} + P_{AA,OP}^{MPSteam} X_{AA,B}^{MPSteam} \tag{3}$$

where $P_{EGAT,OP}^{Electricity}$ = Profit per unit from selling electricity to EGAT during off-peak hours

$P_{AA,OP}^{Electricity}$ = Profit per unit from selling electricity to AA during off-peak hours

$P_{Industry,OP}^{Electricity}$ = Profit per unit from selling electricity to Industry during off-peak hours

$P_{AA,OP}^{LPSteam}$ = Profit per unit from selling LP steam to AA during off-peak hours

$P_{AA,OP}^{MPSteam}$ = Profit per unit from selling MP steam to AA during off-peak hours

3) Model Constraints

Subject to

$$0 \le X_{EGAT,A}^{Electricity} \le 91{,}800 \tag{4}$$

$$0 \le X_{EGAT,B}^{Electricity} \le 91{,}800 \tag{5}$$

$$X_{AA,A}^{Electricity} + X_{AA,B}^{Electricity} = 60{,}000 \tag{6}$$

$$X_{Industry,A}^{Electricity} + X_{Industry,B}^{Electricity} = 140{,}000 \tag{7}$$

$$X_{AA,A}^{LPSteam} + X_{AA,B}^{LPSteam} \ge 11{,}184 \tag{8}$$

$$X_{AA,A}^{MPSteam} + X_{AA,B}^{MPSteam} \ge 906 \tag{9}$$

$$\frac{X_{AA,A}^{LPSteam} + X_{AA,B}^{LPSteam} + X_{AA,A}^{MPSteam} + X_{AA,B}^{MPSteam}}{X_{EAGT,A}^{Electricity} + X_{EGAT,B}^{Electricity} + X_{AA,A}^{Electricity} + X_{AA,B}^{Electricity} + X_{Industry,A}^{Electricity} + X_{Industry,B}^{Electricity} + X_{AA,A}^{LPSteam} + X_{AA,B}^{LPSteam} + X_{AA,A}^{MPSteam} + X_{AA,B}^{MPSteam}} \tag{10}$$

$$X_{EGAT,A}^{Electricity} + X_{AA,A}^{Electricity} + X_{Industry,A}^{Electricity} + X_{AA,A}^{LPSteam} + X_{AA,A}^{MPSteam} \le 149{,}000 \tag{11}$$

$$X_{EGAT,B}^{Electricity} + X_{AA,B}^{Electricity} + X_{Industry,B}^{Electricity} + X_{AA,B}^{LPSteam} + X_{AA,B}^{MPSteam} \le 149{,}000 \tag{12}$$

$$X_{EGAT,A}^{Electricity} + X_{EGAT,B}^{Electricity} + X_{AA,A}^{Electricity} + X_{AA,B}^{Electricity} + X_{Industry,A}^{Electricity} + X_{Industry,B}^{Electricity} + X_{AA,A}^{LPSteam} + X_{AA,B}^{LPSteam} + X_{AA,A}^{MPSteam} + X_{AA,B}^{MPSteam} \le 298{,}000 \tag{13}$$

The dual objectives represented by Eq. (2) and Eq. (3) are to maximize the profits during peak hours and off-peak hours, respectively. Basically, they are the sum of the products of profit per unit and electricity/steam units produced and cannot be combined into a single objective function since the profits per unit for two periods are distinct and the optimal answers of how much electricity and steam to be generated and sold to the clients for both periods must be separately obtained. If only one set of constraints is assigned in a combined single objective, the answers will not be optimal and realistic.

TABLE II
Description of Model Constraints

Equation	Constraint Description
Eq. (4)	The number of electricity units produced and sold to EGAT by Plant A must not exceed 91,800 kW (102% of the CC). Otherwise, the CP will be halved resulting in decreased unit price and profit obtained. Alternatively, nothing produced and sold is possible as EGAT has other SPPs ready, but NPS has to be charged.
Eq. (5)	The number of electricity units produced and sold to EGAT by Plant B must not exceed 91,800 kW (102% of the CC). Otherwise, the CP will be halved resulting in decreased unit price and profit obtained. Alternatively, nothing produced and sold is possible as EGAT has other SPPs ready, but NPS has to be charged.
Eq. (6)	The sum of electricity units produced and sold to AA by Plant A and Plant B must exactly equal to 60,000 kW. Zero unit is not allowed since AA needs electricity for its manufacturing and office buildings.
Eq. (7)	The sum of electricity units produced and sold to Industry by Plant A and Plant B must exactly equal to 140,000 kW. Zero unit is not allowed since Industry needs electricity for its manufacturing and office buildings.
Eq. (8)	The sum of LP steam units produced and sold to AA by Plant A and Plant B must be at least 11,184 kW (in an equivalent unit of electricity). The upper limit is not specified since AA requires tons of steam for its manufacturing.
Eq. (9)	The sum of MP steam units produced and sold to AA by Plant A and Plant B must be at least 906 kW (in an equivalent unit of electricity). The upper limit is not specified since AA requires tons of steam for its manufacturing.
Eq. (10)	According to the SPP cogeneration rule, this constraint is to make sure that the sum of LP steam units and MP steam units generated is minimum 10% of the EGG.
Eq. (11)	To ensure the sum of electricity and steam units produced and sold to all customers must not surpass the maximum capacity of Plant A of 149,000 kW. Please note that the installed generating capacity of Plant A is 164,000 kW but 15,000 kW is used by its station service.
Eq. (12)	To ensure the sum of electricity and steam units produced and sold to all customers must not surpass the maximum capacity of Plant B of 149,000 kW. Please note that the installed generating capacity of Plant B is 164,000 kW but 15,000 kW is used by its station service.
Eq. (13)	To ensure the sum of electricity units and steam units produced and sold to all customers must not surpass the total maximum capacity of both plants of 298,000 kW. Please note that the total installed generating a capacity of Plant A and Plant B is 328,000 kW but 30,000 kW is consumed altogether by their station services.

C. Computation Algorithm

The program utilizes the quantitative determination procedure to further develop a computation algorithm and generate the optimal solutions on how to manage ED of dual cogeneration power plants while achieving the maximum profit. Fig. 4 presents a flowchart of the computation algorithm.

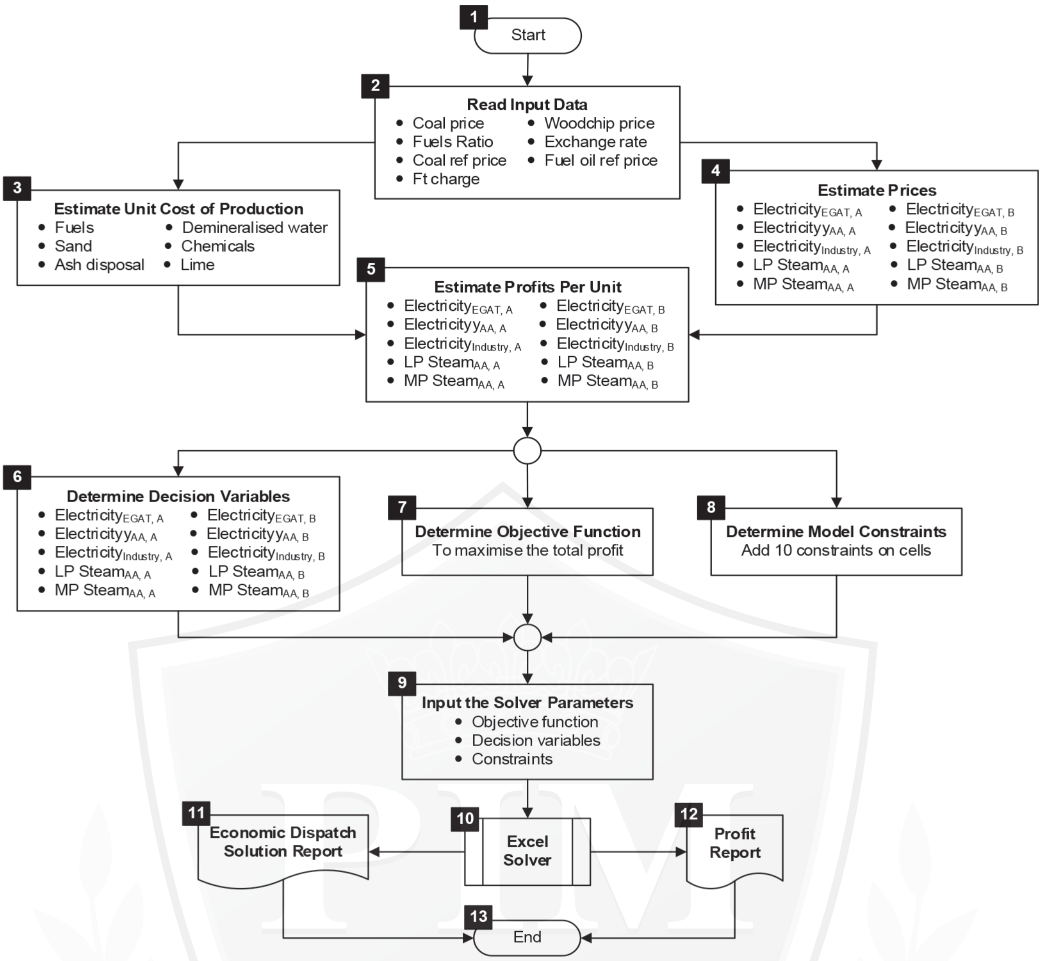


Fig. 4. Flowchart of the computation algorithm

This flowchart can be applied to solve the models for peak and off-peak periods. The computation algorithm starts by reading seven types of input data. The unit cost of production and the prices are estimated using the input data, which can be used to estimate the profits per profit later. Next, the decision variables, the objective function of maximizing the total profit and the model constraints are determined and embedded in cells of the spreadsheets. Then, the Solver Parameters tool in the Microsoft Excel program is input with these three components. Finally, the Excel Solver generates two reports that summarize the model results in terms of ED solution management and profit.

D. Assumptions of the Program

NPS Economic Dispatcher program is subject to the following set of assumptions:

● The unit cost of production is wholly represented by the variable cost, covering mixed fuels of coal and biomass, consumable raw materials and transportations.

● The fuel cost has already been minimised and found that the optimal mixed-fuel ratio is to use 95% of coal and 5% of woodchip as biomass.

● The unit cost of production is the same for electricity and steam when both products are converted into equivalent gross generation (EGG) units.

● All variables and parameters in the models are deterministic (known and constant).

● There is no discount rate on the prices of electricity and steam for all customers.

● The profit per unit is a direct subtraction of the unit cost of production from the selling price per unit. There is no other type of profit considered in this case.

● Heat loss during the generation process is neglected. Input mixed fuels are heated and entirely converted into electricity and steam.

● Power loss in the transmission and the distribution lines is neglected. Total electricity generated can be transmitted to EGAT and distributed to AA and Industry customers.

● Demands for electricity and steam are deterministic. Contract agreements are long-term, and requesting to change capacity at any specifictime is not allowed.

● The SPP cogeneration regulation of minimum 10% heat output remains unchanged.

E. Feasible Scenarios towards Maximum Profit

Considering the total maximum capacity of 298,000 kW, it is impossible to generate and fully sell electricity to EGAT by each plant according to the *CC* of 90,000 kW each. Only 85,910 kW or less (298,000 – 60,000 – 140,000 – 11,184 – 906 = 85,910 kW) is left to be partially sold to EGAT when the generating capacity is fully operated during both periods.

The following two scenarios, as shown in Table 3, were thereby created and used to replace the original constraints of Eq. (4) and Eq. (5). A simulation was performed in the next section to see which of the two allows NPS to achieve the maximum profit.

TABLE III

Two Feasible Scenarios towards Maximum Profit Achievement

Plant	Scenario 1	Scenario 2
A	$MCF \geq 0.51$ $45{,}500 \leq AC \leq 91{,}800$	$MCF \geq 0.51$ $45{,}500 \leq AC \leq 91{,}800$
B	Loss *MCF* AC = 0	Loss *MCF* $15{,}000 \leq AC \leq 45{,}400$

In Scenario 1, Plant A is set to generate and sell electricity between 45,500 kW and 91,800 kW, where the value of *MCF* is 0.51 at a minimum so that *CP* will not be halved. Whilst, Plant B is set to generate and sell nothing to EGAT, where the value of MCF is zero, and the firm will have to be charged some penalty fee.

In Scenario 2, Plant A is set exactly the same as Scenario 1 to avoid a 50% reduction of *CP*. Whereas, Plant B is set to generate and partly sell electricity between 15,000 kW and 45,500 kW to EGAT, where the value of *MCF* is below 0.51 and *CP* is halved.

F. Program Development

NPS Economic Dispatcher was developed using Microsoft Excel 2013 (64-bit) on a notebook computer with Microsoft Windows 10 Pro Operating System and Intel Core i5 Central Process Unit. The users are not required to enable a 'Macro' option before running the program, simply just working with the spreadsheets.

There are eight spreadsheets embedded in the program. The first group of four spreadsheets is for mainly data entry, data processing and data storage: (1) Unit Cost sheet, (2) EGAT Price sheet, (3) AA and Industry Price sheet and (4) Steam Price sheet. The second group of four spreadsheets acts like a display screen showing the objective function, the series of constraints and the results in terms of optimal ED management solutions, profits and a financial penalty, if necessary.

Fig. 5, Fig. 6, Fig. 7 and Fig. 8 illustrate the four display screens and the results of (1) Peak Hours under Scenario 1, (2) Peak Hours under Scenario 2, (3) Off-Peak Hours under Scenario 1 and (4) Off-Peak Hours under Scenario 2, respectively.

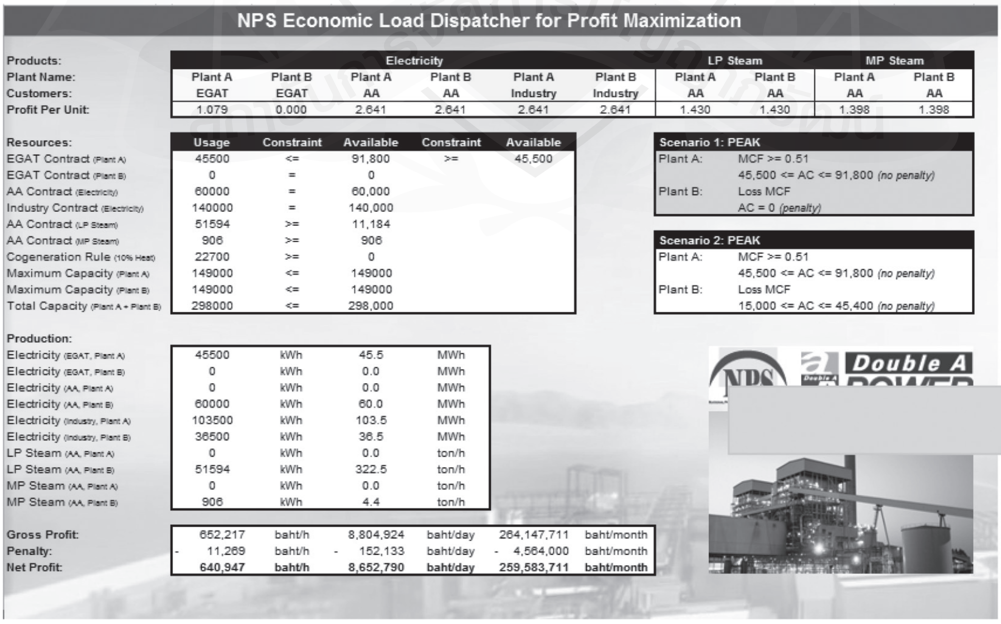
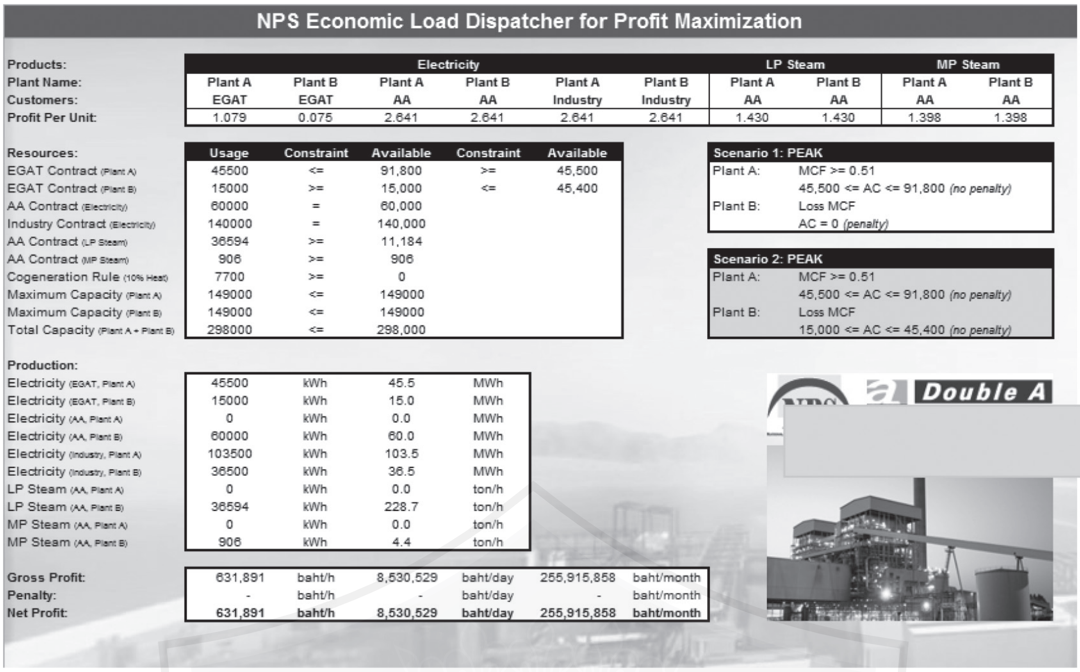


Fig. 5. NPS Economic Dispatcher for peak hours under scenario 1



NPS Economic Load Dispatcher for Profit Maximization

Products:	Electricity						LP Steam		MP Steam	
Plant Name:	Plant A	Plant B	Plant A	Plant B	Plant A	Plant B	Plant A	Plant B	Plant A	Plant B
Customers:	EGAT	EGAT	AA	AA	Industry	Industry	AA	AA	AA	AA
Profit Per Unit:	1.079	0.075	2.641	2.641	2.641	2.641	1.430	1.430	1.398	1.398

Resources:	Usage	Constraint	Available	Constraint	Available
EGAT Contract (Plant A)	45500	<=	91,800	>=	45,500
EGAT Contract (Plant B)	15000	>=	15,000	<=	45,400
AA Contract (Electricity)	60000	=	60,000		
Industry Contract (Electricity)	140000	=	140,000		
AA Contract (LP Steam)	36594	>=	11,184		
AA Contract (MP Steam)	906	>=	906		
Cogeneration Rule (10% Heat)	7700	>=	0		
Maximum Capacity (Plant A)	149000	<=	149000		
Maximum Capacity (Plant B)	149000	<=	149000		
Total Capacity (Plant A + Plant B)	298000	<=	298,000		

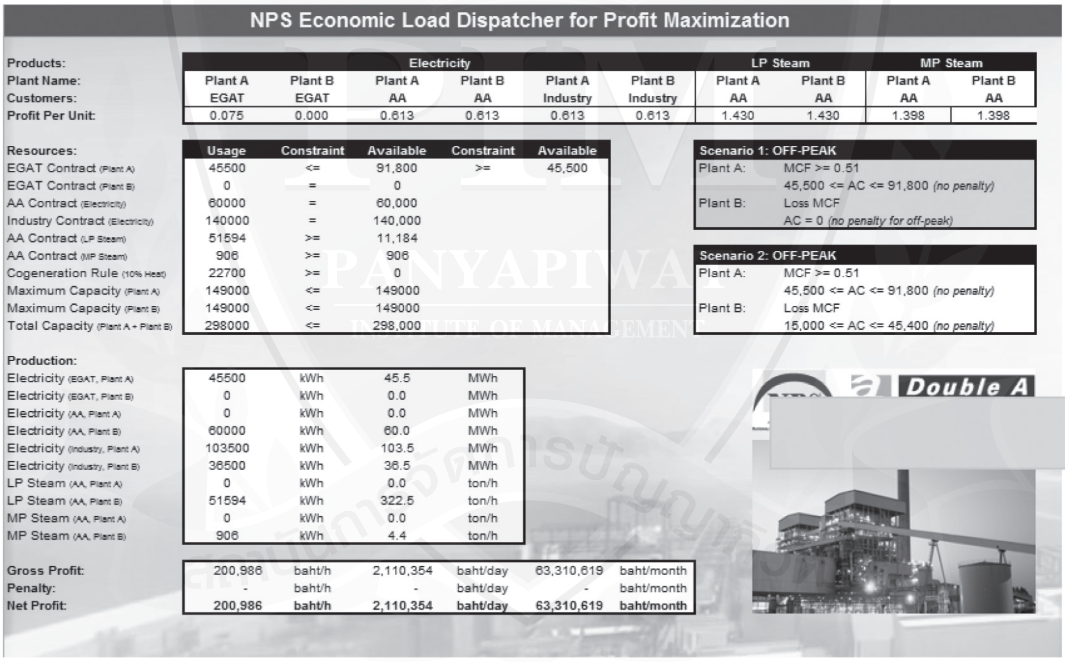
Scenario 1: PEAK
Plant A: MCF >= 0.51
45,500 <= AC <= 91,800 *(no penalty)*
Plant B: Loss MCF
AC = 0 *(penalty)*

Scenario 2: PEAK
Plant A: MCF >= 0.51
45,500 <= AC <= 91,800 *(no penalty)*
Plant B: Loss MCF
15,000 <= AC <= 45,400 *(no penalty)*

Production:				
Electricity (EGAT, Plant A)	45500	kWh	45.5	MWh
Electricity (EGAT, Plant B)	15000	kWh	15.0	MWh
Electricity (AA, Plant A)	0	kWh	0.0	MWh
Electricity (AA, Plant B)	60000	kWh	60.0	MWh
Electricity (Industry, Plant A)	103500	kWh	103.5	MWh
Electricity (Industry, Plant B)	36500	kWh	36.5	MWh
LP Steam (AA, Plant A)	0	kWh	0.0	ton/h
LP Steam (AA, Plant B)	36594	kWh	228.7	ton/h
MP Steam (AA, Plant A)	0	kWh	0.0	ton/h
MP Steam (AA, Plant B)	906	kWh	4.4	ton/h

Gross Profit:	631,891	baht/h	8,530,529	baht/day	255,915,858	baht/month
Penalty:	-	baht/h	-	baht/day	-	baht/month
Net Profit:	631,891	baht/h	8,530,529	baht/day	255,915,858	baht/month

Fig. 6. NPS Economic Dispatcher for peak hours under scenario 2



NPS Economic Load Dispatcher for Profit Maximization

Products:	Electricity						LP Steam		MP Steam	
Plant Name:	Plant A	Plant B	Plant A	Plant B	Plant A	Plant B	Plant A	Plant B	Plant A	Plant B
Customers:	EGAT	EGAT	AA	AA	Industry	Industry	AA	AA	AA	AA
Profit Per Unit:	0.075	0.000	0.613	0.613	0.613	0.613	1.430	1.430	1.398	1.398

Resources:	Usage	Constraint	Available	Constraint	Available
EGAT Contract (Plant A)	45500	<=	91,800	>=	45,500
EGAT Contract (Plant B)	0	=	0		
AA Contract (Electricity)	60000	=	60,000		
Industry Contract (Electricity)	140000	=	140,000		
AA Contract (LP Steam)	51594	>=	11,184		
AA Contract (MP Steam)	906	>=	906		
Cogeneration Rule (10% Heat)	22700	>=	0		
Maximum Capacity (Plant A)	149000	<=	149000		
Maximum Capacity (Plant B)	149000	<=	149000		
Total Capacity (Plant A + Plant B)	298000	<=	298,000		

Scenario 1: OFF-PEAK
Plant A: MCF >= 0.51
45,500 <= AC <= 91,800 *(no penalty)*
Plant B: Loss MCF
AC = 0 *(no penalty for off-peak)*

Scenario 2: OFF-PEAK
Plant A: MCF >= 0.51
45,500 <= AC <= 91,800 *(no penalty)*
Plant B: Loss MCF
15,000 <= AC <= 45,400 *(no penalty)*

Production:				
Electricity (EGAT, Plant A)	45500	kWh	45.5	MWh
Electricity (EGAT, Plant B)	0	kWh	0.0	MWh
Electricity (AA, Plant A)	0	kWh	0.0	MWh
Electricity (AA, Plant B)	60000	kWh	60.0	MWh
Electricity (Industry, Plant A)	103500	kWh	103.5	MWh
Electricity (Industry, Plant B)	36500	kWh	36.5	MWh
LP Steam (AA, Plant A)	0	kWh	0.0	ton/h
LP Steam (AA, Plant B)	51594	kWh	322.5	ton/h
MP Steam (AA, Plant A)	0	kWh	0.0	ton/h
MP Steam (AA, Plant B)	906	kWh	4.4	ton/h

Gross Profit:	200,986	baht/h	2,110,354	baht/day	63,310,619	baht/month
Penalty:	-	baht/h	-	baht/day	-	baht/month
Net Profit:	200,986	baht/h	2,110,354	baht/day	63,310,619	baht/month

Fig. 7. NPS Economic Dispatcher for off-peak hours under scenario 1

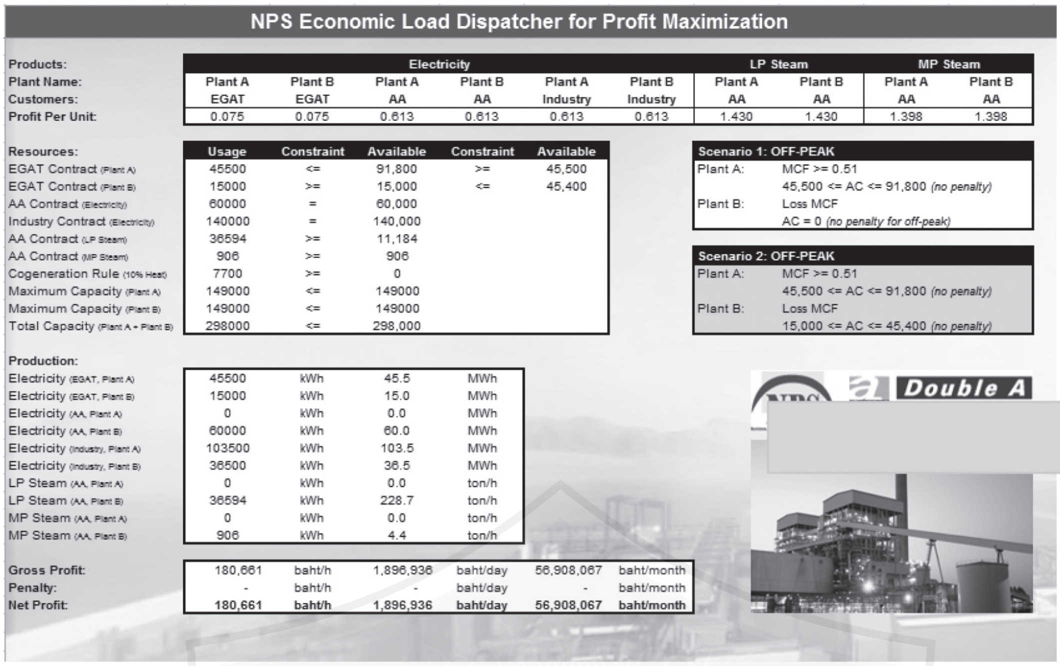


Fig. 8. NPS Economic Dispatcher for off-peak hours under scenario 2

G. Summary of the Illustrative Simulation

Considering the profit report illustrated in Table IV. Scenario 1 is optimal for both peak hours and off-peak hours due to the total maximum net profit of 322,894,330 THB per month relative to Scenario 2 although the company will have to be fined by 4,564,000 THB since no electricity is generated and sold to EGAT during peak hours.

TABLE IV
PROFIT REPORT

Time of Use Scenario	Peak Hours		Off-Peak Hours		24 Hours
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1
Gross Profit	264,147,711	255,915,858	63,310,619	56,908,067	327,458,330
Penalty	(4,564,000)	-	-	-	(4,564,000)
Net Profit	259,583,711	255,915,858	63,310,619	56,908,067	322,894,330

Table V shows the ED management report. In terms of ED management solution when Scenario 1 is chosen due to the optimal profit. It can be observed that the simulation results of Scenario 1 between peak hours and off-peak hours are the same. EGAT partially receives electricity generated by Plant A without losing *MCF* but receives nothing from Plant B in both periods. Whereas, the demands for both electricity and steam of AA and the industry is fully met. LP steam is produced and supplied to AA more than its lower demand limit because the unit profit is greater than the unit profit of MP steam.

TABLE V
Economic dispatch management report

Time of Use Scenario	Peak Hours		Off-Peak Hours	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
$Electricity_A^{EGAT}$	45,500	45,500	45,500	45,500
$Electricity_B^{EGAT}$	0	15,000	0	15,000
$Electricity_A^{AA}$	0	0	0	0
$Electricity_B^{AA}$	60,000	60,000	60,000	60,000
$Electricity_A^{Industry}$	103,500	103,500	103,500	103,500
$Electricity_B^{Industry}$	36,500	36,500	36,500	36,500
$LPSteam_A^{AA}$	0	0	0	0
$LPSteam_B^{AA}$	51,594	36,594	51,594	36,594
$MPSteam_A^{AA}$	0	0	0	0
$MPSteam_B^{AA}$	906	906	906	906

To sum up, the best alternative towards maximum profit achievement can be the one when all demand may not be necessarily fully satisfied according to the contracted capacity. With the underlying ED principle of minimizing total cost together with the proposed program, the performances of NPS should be improved in terms of ED and financial return.

IV. Results and Discussion

NPS Economic Dispatcher program was derived from the desire of the company to consolidate the production and operations planning of its power plants as the current status is now being managed independently without the consideration of ED implementation. The consequences are too much fuel inventory and unplanned maintenance scheduling arising from machine breakdown, affecting the cost to increase while the revenue and the profit from selling electricity and steam to decline consistently over the last few years.

Fig. 9 and Fig. 10 show the revenue and the cost, respectively of electricity and steam by Plant A and Plant B under the best alternative ED solution (Scenario 1), given that their installed capacity accounts for 45.18% of the total (328 out of 726.05 MW), and therefore the revenue and the cost should represent by about the same per cent of the installed capacity.

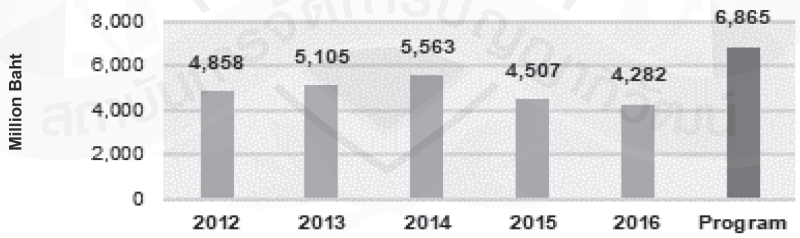


Fig. 9. Revenue from electricity and steam by Plant A and Plant B

The revenue gained from selling electricity and steam has declined from 5,563 million THB in 2014 to 4,282 million THB in 2016 or by 23.03%. This was mainly due to the lack of coordination between the power plants to produce and dispatch electric power and steam to the customers. Also, the decreases in revenue were partially from the effects of significant reductions in coal reference price, fuel oil reference price and Ft charge, which are the key variables used to compute *CP* and *EP* of the electricity prices. Conversely, with the revenue generated by the program, NPS is expected to receive a higher revenue than before, about 6,865 million THB after implementing ED management.

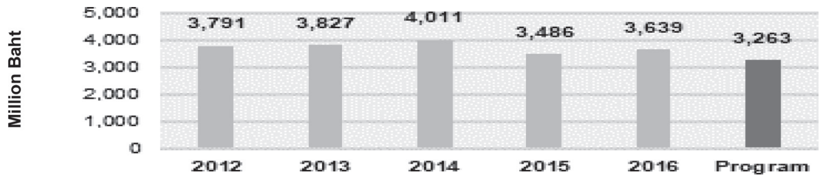


Fig. 10. Cost of electricity and steam production by Plant A and Plant B

Considering the cost of production, it has fluctuated since 2012. This was because of stocking up too much coal fuel and force maintenance cost due to machine breakdown. Over the past five years, an average cost of production represented 77.49% of the revenue; nevertheless, the cost of production generated by the program decreased dramatically to only 47.53% of the revenue after implementing ED management.

Fig. 11 illustrates the profit received from the sales of electricity and steam. Since 2014, the profit has decreased continually from 1,552 million THB to only 644 million THB in 2016, dropping by 58.51%. With the program results, the company's profit should be maximized to 3,552 million THB using Scenario 1.

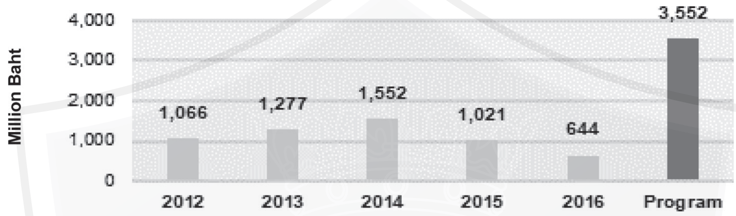


Fig. 11. Profit from electricity and steam by Plant A and Plant B

Table VI below summarises the revenue, cost, profit and EGG per year of Scenario 1. As the Scenario 1 yielded the optimal profit to NPS compared with Scenario 2, the Scenario 1 was therefore chosen for comparison of profit between Scenario 1 and Scenario 2.

TABLE VI

REVENUE, COST, PROFIT AND EGG OF SCENARIO 1

Scenario 1	Revenue [1]	Cost [1]	Profit [1]	EGG [2]
Peak Hours	4,650,693,482	1,835,619,044	2,855,420,818	1,327,590,000
Off-Peak Hours	2,124,120,508	1,427,703,701	696,416,808	1,032,570,000
Total	6,865,364,370	3,263,322,744	3,551,837,626	2,360,160,000

Remark: [1] THB
[2] kWh

Table VII shows the revenue per unit, cost per unit, profit per unit and equivalent gross generation (EGG). It can be seen the total amount of electricity and steam in the equivalent unit of kWh or EGG generated by the program significantly increases to 2,360,000 MWh when ED management is implemented. The average cost per unit is lowered to only 1.383 THB per kWh, while the average revenue per unit and the average profit per unit increase to 2.909 THB per kWh and 1.505 THB per kWh, respectively.

TABLE VII

REVENUE PER UNIT, COST PER UNIT, PROFIT PER UNIT AND EGG

KPI	2012	2013	2014	2015	2016	Program
Revenue Per Unit [1]	3.041	2.985	3.133	2.687	2.435	2.909
Cost Per Unit [1]	2.373	2.238	2.259	2.078	2.069	1.383
Profit Per Unit [1]	0.668	0.747	0.874	0.609	0.366	1.505
EGG [2]	1,597	1,710	1,775	1,677	1,759	2,360

Remark: [1] THB per kWh
[2] '000 MWh

Overall, Scenario 1 generated the same optimal ED management decision for both times of use. EGAT has not dispatched electricity according to the amount of *CC* with both plants. For Plant A, only 45.5 out of 90 MWh was sold to EGAT to maintain *MCF* of at least 51% so that *CP* would not be deducted by 50% that could result in the selling price to be very cheap. For Plant B, the report suggests that NPS should not produce and sell anything to EGAT although the company had to be charged due to unavailability. The reason for this is because NPS had to fully or at minimum supply electricity and electricity to AA and Industry customers first, see the model constraints since they could not operate manufacturing in their factories without electric power or steam. With this, 85.91 MW or less was remained for supplying to EGAT from both of the plants and that is why it was really impossible to fully meet *CC* with EGAT regardless of either Plant A or Plant B. However, it is the best scenario alternative that allows NPS to achieve the maximum profit in the end.

Fig. 12 presents the sensitivity report of Peak Scenario 1) from Excel Solver after solving the economic dispatch problem with the objective of achieving maximum profit. This sensitivity report assists a decision maker to know whether the solution is relatively insensitive to reasonable changes in one or more of the parameters of the problem.

From the sensitivity report, the solution values on how much electricity and steam to be generated and dispatched to each of the customers are shown in the Final Value column of the Variable Cells panel. It can be seen that all the customers, except EGAT, were fully satisfied according to the amounts of contracted capacity shown in the Final Value of the Constraints panel. Some customers were even supplied more than they want, such as LP steam to AA, but that was not going to result in any consequences.

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [NPS Economic Dispatcher.xlsx] Peak (Scenario 1)
Report Created: 16:19:46

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
C21	Electricity Sold to EGAT by Plant A	45500	0	1.0786	0.3512	1E+30
C22	Electricity Sold to EGAT by Plant B	0	0	0.0000	1E+30	1E+30
C23	Electricity Sold to AA by Plant A	0	-1.77636E-15	2.6405	1.77636E-15	1E+30
C24	Electricity Sold to AA by Plant B	60000	0	2.6405	1E+30	1.77636E-15
C25	Electricity Sold to Industry by Plant A	103500	0	2.6405	1E+30	0
C26	Electricity Sold to Industry by Plant B	36500	0	2.6405	0	1E+30
C27	LP Steam Sold to AA by Plant A	0	0	1.4298	0	1E+30
C28	LP Steam Sold to AA by Plant B	51594	0	1.4298	1E+30	0
C29	MP Steam Sold to AA by Plant A	0	0	1.3978	0	1E+30
C30	MP Steam Sold to AA by Plant B	906	0	1.3978	0.0320	0

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C11	Electricity CC with AA	60000	1.2107	60000	22700	60000
C13	LP Steam CC with AA	51594	0	11184	40410	1E+30
C14	MP Steam CC with AA	906	-0.0320	906	40410	906
C15	SPP Cogeneration Rule	22700	0	0	22700	1E+30
C9	Electricity CC with EGAT (Plant A)	45500	0	91800	1E+30	46300
C9	Electricity CC with EGAT (Plant A)	45500	-0.3512	45500	22700	36500
C10	Electricity CC with EGAT (Plant B)	0	-1.4298	0	22700	0
C12	Electricity CC with Industry	140000	1.2107	140000	22700	36500
C16	Maximum Capacity of Plant A	149000	0	149000	36500	4.36557E-11
C17	Maximum Capacity of Plant B	149000	0	149000	1E+30	4.36557E-11
C18	Total Maximum Capacity	298000	1.4298	298000	4.36557E-11	25222.22222

Fig. 12. Sensitivity Report for NPS Economic Dispatcher Peak (Scenario 1)

In the Variable Cells panel, information about the effect of changes to the objective function coefficients are presented. The upper and the lower limits to which the coefficients of profit per unit of electricity or steam can be changed without impacting the optimality of the original solution is revealed by the values in the Allowable Increase and the Allowable Decrease columns. For example, the allowable increase in the objective function coefficient for Electricity Sold to EGAT by Plant A is 0.3512 THB. This means that if the unit profit of Electricity Sold to EGAT increases to 1.2000 THB (i.e. an increase of 0.1214 THB from the current value of 1.0786 THB), it is still optimal to generate and sell the numbers of electricity and steam units to the customers specified in the Final Value column.

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [NPS Economic Dispatcher.xlsx] Off-Peak (Scenario 1)
Report Created: 16:43:03

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
C21	Electricity Sold to EGAT by Plant A	45500	0	0.0748	1.3550	1E+30
C22	Electricity Sold to EGAT by Plant B	0	0	0	1E+30	1E+30
C23	Electricity Sold to AA by Plant A	0	-2.22045E-16	0.6127	2.22045E-16	1E+30
C24	Electricity Sold to AA by Plant B	60000	0	0.6127	1E+30	2.22045E-16
C25	Electricity Sold to Industry by Plant A	103500	0	0.6127	1E+30	0
C26	Electricity Sold to Industry by Plant B	36500	0	0.6127	0	1E+30
C27	LP Steam Sold to AA by Plant A	0	0	1.4298	0	1E+30
C28	LP Steam Sold to AA by Plant B	51594	0	1.4298	1E+30	0
C29	MP Steam Sold to AA by Plant A	0	0	1.3978	0	1E+30
C30	MP Steam Sold to AA by Plant B	906	0	1.3978	0.0320	0

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C11	Electricity CC with AA	60000	-0.8171	60000	22700	60000
C13	LP Steam CC with AA	51594	0	11184	40410	1E+30
C14	MP Steam CC with AA	906	-0.0320	906	40410	906
C15	SPP Cogeneration Rule	22700	0	0	22700	1E+30
C9	Electricity CC with EGAT (Plant A)	45500	0	91800	1E+30	46300
C9	Electricity CC with EGAT (Plant A)	45500	-1.3550	45500	22700	36500
C10	Electricity CC with EGAT (Plant B)	0	-1.4298	0	22700	0
C12	Electricity CC with Industry	140000	-0.8171	140000	22700	36500
C16	Maximum Capacity of Plant A	149000	0	149000	36500	3.63798E-11
C17	Maximum Capacity of Plant B	149000	0	149000	1E+30	3.63798E-11
C18	Total Maximum Capacity	298000	1.4298	298000	3.63798E-11	25222.22222

Fig. 13. Sensitivity Report for NPS Economic Dispatcher Off-Peak (Scenario 1)

Fig. 13 shows the sensitivity report for Off-Peak under Scenario 1. The numbers of electricity and steam to be sold to the customers are exactly the same as Peak under Scenario 1. However, the objective function coefficients are changed as the profit per unit between peak hours and off-peak hours are distinct. In this case, the allowable increase in the objective function coefficient for Electricity Sold to EGAT by Plant A is 1.3550 THB. This indicates if the unit profit of Electricity Sold to EGAT rises to 1.0748 THB (i.e. a rise of 1 THB from the current value of 0.0748 THB), the ED management solution is still optimal.

V. Conclusion

This paper developed a spreadsheet-based optimization program for strategically managing economic dispatch of electricity and steam for the dual power plants to ultimately achieve the maximum profit. The development of *NPS Economic Dispatcher* was derived from the independent managed production and operations without the applications of economic dispatch among the power plants. As a consequence, the revenue has been affected and the profit has been declining consecutively for the last few years.

Apart from the decreases in revenue and profits, lack of coordination among the power plants results in the cost of goods sold to increase even more units of electricity and steam could be sold over years. This is in a contrast to what it should have actually been in both theory and real practices. Fig. 14 illustrates the comparison between the profit from selling electricity and steam over the last five years and the profit generated by the developed program.

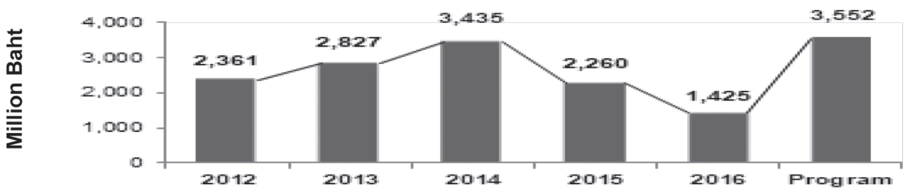


Fig. 14. Profit from Electricity and Steam in the Past 5 Years and from the Program

It can be clearly seen that the program yielded the optimal annual profit resulting from applying and well-managed economic dispatch of the dual power plants. The profit generated by NPS Economic Dispatcher of 3,552 million THB can be calculated from the sum of monthly profit from peak hours under Scenario 1 of 259,583,711 THB and monthly profit from off-peak hours under Scenario 1 of 63,310,619 THB, multiplied by eleven months, given that one month is for yearly plant maintenance outage.

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Effect of pre-cooling treatment, 1-methylcyclopropene (1-MCP) and controlled atmosphere (CA) on vase life of cut spray carnation flowers

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***Abstract*— The vase life of 'Light Pink Barbara' (LPB) and 'Boundee' (BD) after treatment with pre-cooling at 5°C for 48 h (dark condition), 1-MCP treatment by EthylBloc® (EB) sachet for 6 h and CA (CO_2 20% and O_2 5% at 5°C for 12, 24 and 48 h) has been investigated. All treatments decreased ethylene production in both cultivars 'LPB' and 'BD'. Pre-cooling treatment prolonged the vase life of 'LPB' but induced senescence in 'BD'. The vase life of both cut spray carnations were prolonging after by 1-MCP treatment in the form of EB. CA treatments prolonged the vase life of 'LPB' cut single carnation flowers while decreased vase life of 'BD'. The vase life of multiple flowers on a stem of 'LPB' was prolonged by pre-cooling, 1-MCP and CA for 12 h treatments. Treatments with CA for 24 h and 48 h enhanced the senescence in 'LPB'. The vase life of multiple flowers on a stem of 'BD' prolonged by 1-MCP treatment, but reduced by pre-cooling and all CA treatments. These finding suggest that CA treatment was useful to prolong the vase life and maintain the quality of 'LPB' during transportation and display.**

***Index Team* — Carnation, Vase life, Controlled Atmosphere, 1-MCP, Senescence**

I. Introduction

Carnation (*Dianthus caryophyllus* L.) is one of the most important commercial cut flowers in many countries around the world. The vase life of cut flower is the main determinant of ornamental cut flower value commercially [1]. In carnation, loss of qualities such as early sleepiness (in-rolling of the petals), wilting, unbloomed florets (blasting), and yellowing of leaf are major problems during the postharvest phase. Variation in the postharvest life is effect of differences in autocatalytic production of endogenous ethylene, stress-induced ethylene production and exogenous ethylene sensitivity [2]. 1-Methylcyclopropene (1-MCP, EthylBloc) is an ethylene analog was shown to be very effective inhibitor of ethylene action in ornamentals, fruits and vegetables [3]. Recently, 1-MCP has been commercial application for reduce the ripening process, maintain quality and extending the postharvest shelf life in a wide range of plant products [4].

Although controlled atmosphere (CA) has been used commercially for a long time, the mode action of low level of O_2 and high level of CO_2 in delaying plant senescence in fruits and vegetables [5]. However, very few reports on the effects of CA on the quality, production of ethylene and the vase life of spray type cut carnation. The aim of the present research was to determine the effects of pre-cooling treatment, 1-MCP and CA condition on extending the vase life of spray type cut carnation.

II. Materials and Methods

A. Plant materials

Cut flowers of carnations (*Dianthus caryophyllus* L.) cultivars 'Light Pink Barbara' (LPB) and 'Boundee' (BD); spray type carnations were used in this research. The potted carnation plants were cultivated and held under a natural day-length condition in a greenhouse (20°C minimum and 30°C maximum) in Utsunomiya University Tochigi prefecture Japan. The flowers at the commercial stage of flowering, at the first flower out of 6-8 flower buds on all stem were mostly open, were harvested in the morning. All cut stems were transfer to laboratory within 1 h. All multiple cut flower stems were prepared to have totally five or six flowers and buds. Removing the immature tight buds on each stem has to operate.

In the experiments with single flowers, the open flowers stage V (Fig. 1.) was the stage which their outermost petals had just reached right angles to the stems. Each treatment had five replicate flowers.

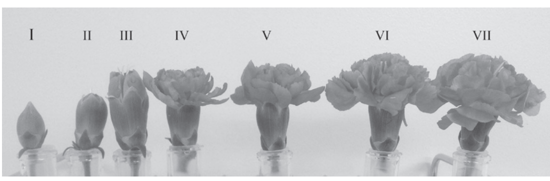

Fig. 1. Stages of carnation flower

B. Pre-cooling method

Cut carnation flowers were placed into the temperature controlled storage room at 5˚C and 75±5% relative humidity (RH) under the dark condition for 48 h.

C. 1-MCP Treatment using EthylBloc® (EB) sachet

The cut carnation flowers were place in test tube contained with distilled water, all flowers treated with 4 EthylBloc® (EB) sachets (a.i., 0.014%) in the 50×28×28 cm plastic boxes at 20˚C and 75±5% RH for 6 h.

D. CA treatments

Cut carnation flowers stem were held in the bottles contained with 50 mL distilled water. All bottles were hold in CO_2 incubator (CO_2 multi gas incubator WMI 165-R, ASTEC, Fukuoka, Japan) generated CO_2 concentrations to 20% and O_2 5% at 5°C and 75±5% RH for 12, 24 and 48 h, respectively.

E. Measurement of ethylene production

Individual flowers with stem length for 10 cm were prepared for measurement. The flowers were contained in the plastic bottles size 750 mL (one flower each bottle), and left at 20 °C for 1 h. Gas samples (l-mL) were taken from the sampling port on the bottle's lid. Ethylene concentration was determine by gas chromatography with a flame ionization detector (model GC-15 A, Shimadzu, Kyoto, Japan) using an activated alumina column (2.0m×3.0mm I.D., Shinwa Chemical Industries Ltd. Kyoto, Japan) according to Yamane et.al (2007) [6]. Data were expressed per gram flower fresh weight.

F. Statistical analysis

Data were analyzed with the JMP (SAS Institute Inc., Cary, NC, USA) statistical software program using Student's *t*-test and ANOVA. Data were tested by Tukey-kramer test for mean separation among treatments when ANOVA was significant ($P < 0.05$).

III. Results and discussion

A. Effect of short-term CA on the production rate of ethylene in cut flowers

In control flowers, ethylene production was low during the first 4 days then sharply increased and reached a maximum at day 6 (14.78 $nLC_2H_4 \cdot g^{-1} \cdot h^{-1}$) and decreased thereafter. Treated flowers shown ethylene production at low level throughout the experiment period (Fig. 2a). These results show that the treatments inhibited ethylene of 'LPB'. Treatment with CA for 12 and 24 h stimulated ethylene production of 'BD'. Stimulation was stronger in CA 12 h than those 24 h treatments and reached maximum at day 2. The climacteric peak of CA 12 h and 24 h treatments were 143.55 and 47.91 $nLC_2H_4 \cdot g^{-1} \cdot h^{-1}$, respectively (Fig. 2b).

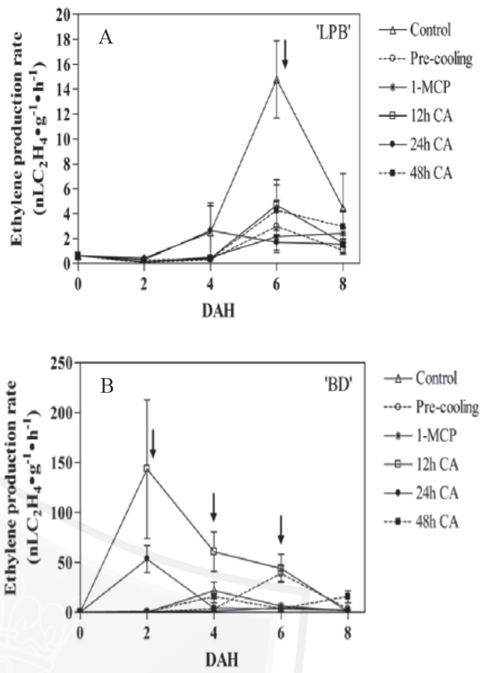

Fig. 2. Ethylene production cut carnation flowers 'LPB' (A) and 'BD' (B) during vase life. After treatments, all flowers were kept under 15 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (PPFD, 12h) at 75±5% RH and 20°C. The vertical bar indicates Standard Error (SE) (*n*=5).

Previous study noted that the CA with high CO_2 treatments inhibit the production of ethylene result to maintained the quality and delaying the initiation of senescence [7]. Treating fruits and vegetables with high level of CO_2 can have beneficial effects on inhibited the production of ethylene. It is due to high level of CO_2 can compete with ethylene on binding sites at the ethylene receptor [8]. In earlier experiments, point to another site of inhibition by CO_2. In case of tomato, high levels of CO_2 suppress the expression of ethylene-dependent and ethylene-independent ripening-associated genes [9]. However, high CO_2 conditions result to anaerobic respiration, causing a severe deterioration of the overall appearance of plant species [10].

Numerous experiments on various cut flowers reported that 1-MCP inhibited effects of exogenous ethylene, such as wilting, petal or flower abscission and other senescence symptoms [11-12].

It is believed that 1-MCP molecules bind permanently to the ethylene binding protein (EBP) at the ethylene receptors site in carnation tissue [13]. The combination of 1-MCP and high level of CO_2 condition may be a feasible technique to extend the postharvest shelf life of mint [14], similar to the findings in the present study. The primary responses to CA storage (high CO_2 and low O_2) has also been shown reduced the respiration rate (i.e. O_2 uptake), which can be prolonged the storage life, vase life and reduced degradation rate of soluble pectin [15]. The second responses, important beneficial reactions include a reduction ethylene synthesis and perception, reduce chlorophyll degradation, reduce cell wall degradation, and reduced phenolic oxidation.

It has been reported that 1-MCP inhibits ethylene biosynthetic enzymes such as ACO and ACS. It has also been reported that continuous CO_2 treatment and 1-MCP inhibit the accumulation of mRNA of ethylene biosynthesis genes [16-17]. In this study, pre-cooling, 1-MCP, high CO_2 concentrations in CA inhibited the production of ethylene, suppress the expression of ethylene biosynthesis genes including *DcACS2*, *DcACS3*, and *DcACO1* in the gynoecium and petal tissues of carnation florets [18]. There is strong evidence in carnation flowers that the activities of ACC synthase and ACC oxidase enzymes higher when the production of ethylene increased [19-20].

B. Effect of short-term CA storage on vase life of cut single carnation flowers

The treatments were not significantly prolonged the vase life of cut single flowers 'LPB' (Fig. 3a). However, 1-MCP prolonged the vase life of 'BD', while CA treatments decreased the vase life by exhibited senescence of cut single flowers 'BD' (Fig. 3b) In earlier experiments, high level of CO_2 prior to storage could have injury symptoms on cucumbers when stored at low temperatures [21]. The negative metabolic responses to low O_2 condition included aroma biosynthesis in fruit including apple, banana, peach and other agricultural commodities [22].

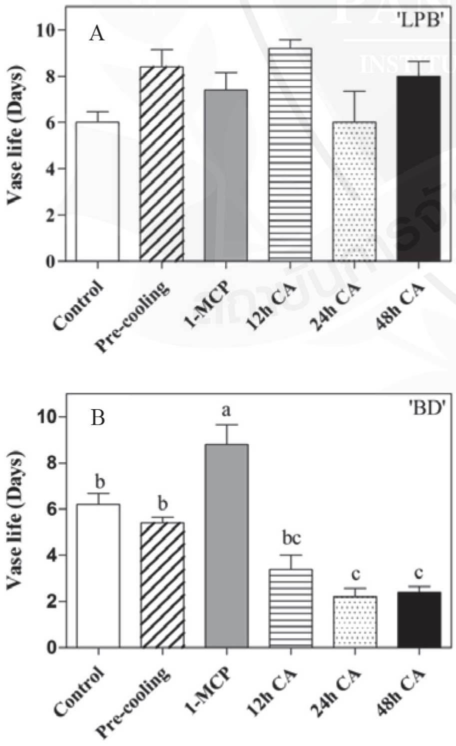

Fig. 3. Effect of the treatments on the vase life (days) of cut single carnation flowers 'LPB' (A) and 'BD' (B). After treatments, all flowers were kept under 15 µmol·m^{-2}·s^{-1} (PPFD, 12h) at 75±5% RH and 20°C. The vertical bar indicates Standard Error (SE) (*n*=5).

C. Effect of short-term CA on vase life of multiple flowers on a stem

The multiple flowers on a stem of cut carnations shown negative effected when exposed to high CO_2 for long times. Flowers of 'LPB' treated with pre-cooling, 1-MCP and 12 h CA shown the vase life longer than that in the control (Fig. 4a). However, the CA treatment for 24 and 48 h exhibited disorder symptom like-skin burning at sepals of flower buds. From Fig. 4., pre-cooling 1-MCP, CA 12 and 24 h treatment prolonged the vase life of 'BD' longest 1-MCP (17 days). Treatment with CA 48 h. induced disorder symptom like-skin burning at sepals of 'BD'. These results related with previous studies, 1-MCP treatment prevented abscission of Pelargonium [23], *Alstroemeria* L. and *Antirrhinum majus* L. [24]. Controlled Atmosphere (high level of CO_2 condition) inhibits ethylene production [25] and delay senescence of carnation [26]. However, the effect of CA also depended on CO_2 and O_2 concentration, plant verities and duration of treatment.

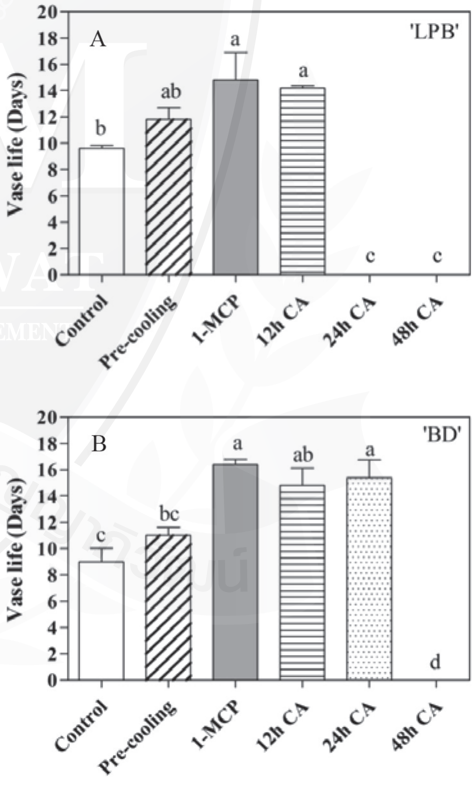

Fig. 4. Effect of the treatments on the vase life (days) of multiple flowers on a stem 'LPB' (A) and 'BD' (B). After treatments, all flowers were kept under 15 µmol·m^{-2}·s^{-1} (PPFD, 12 h) at 75±5% RH and 20°C. The vertical bar indicates Standard Error (SE) (*n*=5).

IV. Conclusion

The results suggest that CA treatment for 12 h was useful to prolong the vase life and maintain the quality of 'LPB' during transportation and display. Understanding the role of CA in flower senescence may lead to development of both chemical and physical techniques to delay the senescence of flower that are economically detrimental, and extend the postharvest life of cut spray carnation flowers. However, the concentration of CO_2 and O_2, plant verities and duration of treatment should be considered.

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Mechanical Properties of Fused Deposition Modeling Parts

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Abstract—**This research aimed to study effect of fabrication parameters on the mechanical property of three-dimensional printing part. Materials used in this study was Acrylonitrile butadiene styrene. There were two sections of experiments. The first section focused on the effect of the layer thickness and in-fill on the mechanical properties whereas the second section focused on the effect of built orientation on the mechanical properties. All samples were fabricated using Fused Deposition Modeling (FDM) technique. The samples' geometry was according to ASTM-D638 Type I. Values of mechanical property were obtained by tensile test. According to the result, it had been found that the in-fill and built orientation were influenced parameters to mechanical property. No significant change in the mechanical property was observed for different layer thickness.**

Index Terms—**Three-dimensional Printing, Fused Deposit Modeling, Mechanical Property**

I. Introduction

Three dimensional fabrication (3D-F) technology has become increasingly important nowadays in many field of industries with different purposes, for example automotive component manufacturing [1], aircraft component manufacturing [2], mold and die [3], and medical use [4]. 3D-F technology is based on layer manufacturing technique which is to additively deposit material layer-by-layer. Key advantage of 3D-F is an ability to manufacture complicated geometry products which conventional manufacturing processes such as Computer Numerical Control (CNC) milling/turning or other forming methods cannot be performed [2].

The principle of 3D-F is to convert 3D Computer Aided Design (CAD) model into stack of two-dimensional (2D) cross-sectional layers along vertical direction [6] (normally Z axis). Each cross-sectional layer (normally XY plane) composes of geometric model boundary. Area inside the boundary is where the material will be filled to construct the physical part [5]. During the fabrication process, the lowest 2D cross-sectional layers is printed first whereas the higher 2D cross-sectional layers are printed later until it reaches to the highest 2D cross-sectional layer.

Nowadays, there are several of 3D-F system available for different materials type, i.e. ceramics, metal and polymer. Current designation of system is commonly based on material type of method of production. Some of 3D-F are provided below:

1) *3D metal fabrication*

It is also known as selective laser melting/sintering (SLM/SLS). It is a technique where the laser is used to fuse the power of material for constructing physical part [2]. Common materials which can be fabricated using this 3D-F are cobalt-chromium [6], stainless steel [2], and titanium [7].

2) *Stereolithography apparatus (SLA)*

It is a method where laser is used to cure the liquid monomer to solid polymer (forming crosslink network in material) for constructing physical part. Common polymeric materials which can be fabricated using this 3D-F is epoxy-base polymer [8]. In addition, SLA can also be applied to construct ceramics parts by mixing ceramics into monomer liquid. After the part is solidified, ceramics is trapped inside. After that polymer is burnt and leaves the polymer ceramic structure.

3) *Fused Deposit Modeling*

It is a method where the polymer is melted by heat and inject through the nozzle to deposit the material on platform [9]. A wide range of polymer can be fabricated using this technique including, Polyethylene Terephthalate (PET) [10], Acrylonitrile butadiene styrene (ABS) [10], Polylactic-acid (PLA) [11] etc.

In this paper, Fused Deposit Modeling (FDM) is under interest which it is widely used across the industries. Many of FDM finished parts tend to be used for geometric prototyping, where many of them can also be used as products. For purpose of fabrication for product, mechanical properties of finished part is significant. This is because part needs to have sufficient strength to withstand loads. In addition, product development process using Computer Aided Engineering (CAE) technology, mechanical properties are used as an input of calculation in CAE and confirms the usability based on CAE result. There is limited study on the mechanical properties of materials fabricated from FDM. To best of authors' knowledge, previous studies on 3D-F has intensively focused on 3D metal fabrication [2, 6, 7] and SLA [2, 8]. Even studies on FDM have been conducted [2, 10, 11], but the effect of the parameters on mechanical property based on software options attached to the machine.

In order to provide data of FDM parts which will be used further in many purpose as aforementioned. This study assesses their mechanical properties based on various fabrication parameters has not been studied yet.

II. Methodology

Three level orthogonal array (full factorial DOE) technique was used to create experimental set. The fabrication parameters considered in DOE includes layer thickness, in-fill, and part built orientation. Each of parameters has its definition as follows:

1) Layer Thickness

It is an interval of material deposition layer along vertical axis in FDM process.

2) In-fill

The density of material deposited inside FDM part. Higher in-fill means denser part.

3) Built orientation

The direction which FDM part is built.

Material used for mechanical test was ABS which its mechanical properties were shown Table I. All samples were fabricated with Zortrax M200. The software which used to prepare manufacturing conditions and generate the code for machine control was Z-suit v1.12.2.

TABLE I

Mechanical Properties of ABS material used in this experiment [12]

Mechanical Properties	Metric	Test Method
Tensile Strength	30.46 MPa	ISO 527:1998
Breaking Stress	25.89 MPa	ISO 527:1998
Elongation at max Tensile Stress	4.52%	ISO 527:1998
Elongation at Break	11.08%	ISO 527:1998
Bending Stress	46.30 MPa	ISO 178:2011
Flexural Modulus	1.08 GPa	ISO 178:2011
Izod Impact, Notched	8.93 kJ/m2	ISO 180:2004

The experiment was divided into two sections. First section focused on layer thickness and in-fill. For second section, only one condition in the first experiment was selected for fabricating in various built orientations to study effect of built orientation to mechanical property.

A. Experimental Design

In Z-suit v1.12.2 (normal print setting mode), it provides a wide range of layer thickness selection in fixed values and provides three fill-in conditions (Maximum, High, Medium, and Low).

For the first section of experiment which aimed to study effect of layer thickness and in-fill to mechanical property. Then, the three levels are identified as in Table II.

TABLE II

Designation of Parameters in Each Level

Level	Layer Thickness (mm)	In-fill
1	0.09	Low
2	0.14	Medium
3	0.19	High

For full factorial design with three level for each parameter (3^2), it has total of 9 experimental condition as summarized in Table III.

TABLE III

Designation of Parameters in Each Level

Condition	Layer Thickness (mm)	In-fill	Specimen Weight (g)
1	0.09	Low	15
2	0.09	Medium	16
3	0.09	High	17
4	0.14	Low	15
5	0.14	Medium	16
6	0.14	High	17
7	0.19	Low	15
8	0.19	Medium	16
9	0.19	High	17

Experimental condition No.9 is selected to test effect of built orientation to mechanical property. There was flat, edge, and upright orientation [8, 9], as shown in Fig. 1. Therefore, additional three experimental conditions were included.

B. Specimens and Fabrication

Specimens were created as 3D geometric model which dimension specified according to the ASTM D638 standard Type I specimen [13]. Samples had 165 mm in total length, 57 mm in length of narrow section, and 7 mm in thickness.

Three sample were tested for each conditions (n=3). This allows calculation of average and standard deviation of all interested mechanical values. In fabrication process, the nozzle diameter of 0.4 mm and the filament diameter of 1.75 mm were used. In addition, extruder temperature of 380^{o}C, heating bed temperature of 80^{o}C was set.

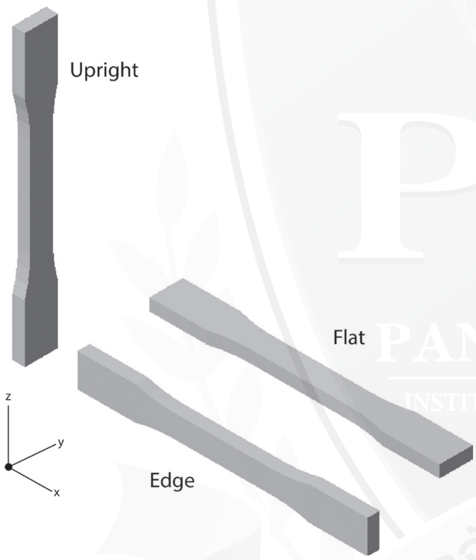

Fig. 1. Build Orientation

All samples in the first section of experiment were fabricated in edge orientation whereas the second section of experiment were fabricated in edge, flat, and upright orientation. Fig. 2 shows the fabrication process.

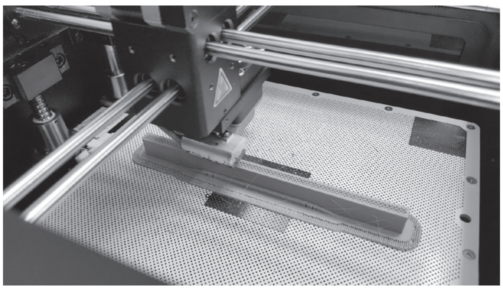

Fig. 2. Sample Fabrication

C. Tensile Test

The mechanical properties of all specimens were examined by using the Universal Testing Machine (UTM) (Instron 5982, Instron Inc., U.S.A). Specimen were attached with the extensometer to measure the displacement. The tests were performed at room temperature with a constant crosshead speed of 5 mm/min, as shown in Fig. 3. The load was applied to the specimen until the test specimen until fractures. Elastic modulus, yield strength, elongation at yield, ultimate tensile strength (UTS), and elongation at UTS were measured of calculated accordingly.

Fig. 3. Tensile Test

III. Result

For the results of tensile tests of the FDM parts, average values of Elastic Modulus (ES), Yield Strength (YS), Ultimate Tensile Strength (UTS), elongation at YS, and elongation at UTS are in consideration. Table IV shows the effect of layer thickness and in-fill to these properties whereas Table V shows the effect of built orientation on the mechanical property. Fig. 4 shows the stress-strain curve for specimens fabricated by each condition in the first section of experiment whereas Fig. 5 shows the stress-strain curve for specimens fabricated by each condition in the second section of experiment.

TABLE IV
EFFECT OF LAYER THICKNESS AND IN-FILL CONDITIONS TO MECHANICAL PROPERTIES

Condition	Layer Thickness (mm)	In-fill	E (MPa)	YS (MPa)	UTS (MPa)	Elongation at YS (%ε)	Elongation at UTS (% ε)
1	0.09	Low	902.15 ± 21.38	12.63 ± 0.10	14.90 ± 0.20	1.59 ± 0.02	2.36 ± 0.21
2	0.09	Medium	945.44 ± 46.05	13.15 ± 0.43	14.90 ± 0.72	1.58 ± 0.02	2.23 ± 0.11
3	0.09	High	953.31 ± 73.49	13.20 ± 0.89	15.00 ± 1.19	1.58 ± 0.02	2.28 ± 0.04
4	0.14	Low	887.87 ± 17.54	12.85 ± 0.47	13.90 ± 0.37	1.64 ± 0.05	2.07 ± 0.04
5	0.14	Medium	950.73 ± 16.83	13.44 ± 0.26	14.60 ± 0.20	1.61 ± 0.05	2.08 ± 0.06
6	0.14	High	976.28 ± 5.66	13.93 ± 0.41	15.30 ± 0.48	1.62 ± 0.03	2.09 ± 0.04
7	0.19	Low	885.27 ± 11.35	13.21 ± 0.09	14.40 ± 0.04	1.69 ± 0.03	2.19 ± 0.01
8	0.19	Medium	919.84 ± 21.34	13.22 ± 0.11	14.40 ± 0.01	1.63 ± 0.05	2.09 ± 0.01
9	0.19	High	891.37 ± 9.80	13.28 ± 0.32	15.20 ± 0.18	1.68 ± 0.04	2.33 ± 0.03

TABLE V
EFFECT OF ORIENTATION TO MECHANICAL PROPERTIES

Layer Thickness (mm)	In-fill	Orientation	ES (MPa)	YS (MPa)	UTS (MPa)	Elongation at YS (% ε)	Elongation at UTS (% ε)
0.09	High	Edge	891.37 ± 9.80	13.28 ± 0.32	15.20 ± 0.18	1.68 ± 0.04	2.33 ± 0.03
0.09	High	Flat	774.07 ± 35.12	12.00 ± 0.34	13.15 ± 0.43	1.47 ± 0.06	2.38 ± 0.05
0.09	High	Upright	1021.57 ± 20.04	5.18 ± 0.95	5.18 ± 0.95	0.53 ± 0.08	0.53 ± 0.08

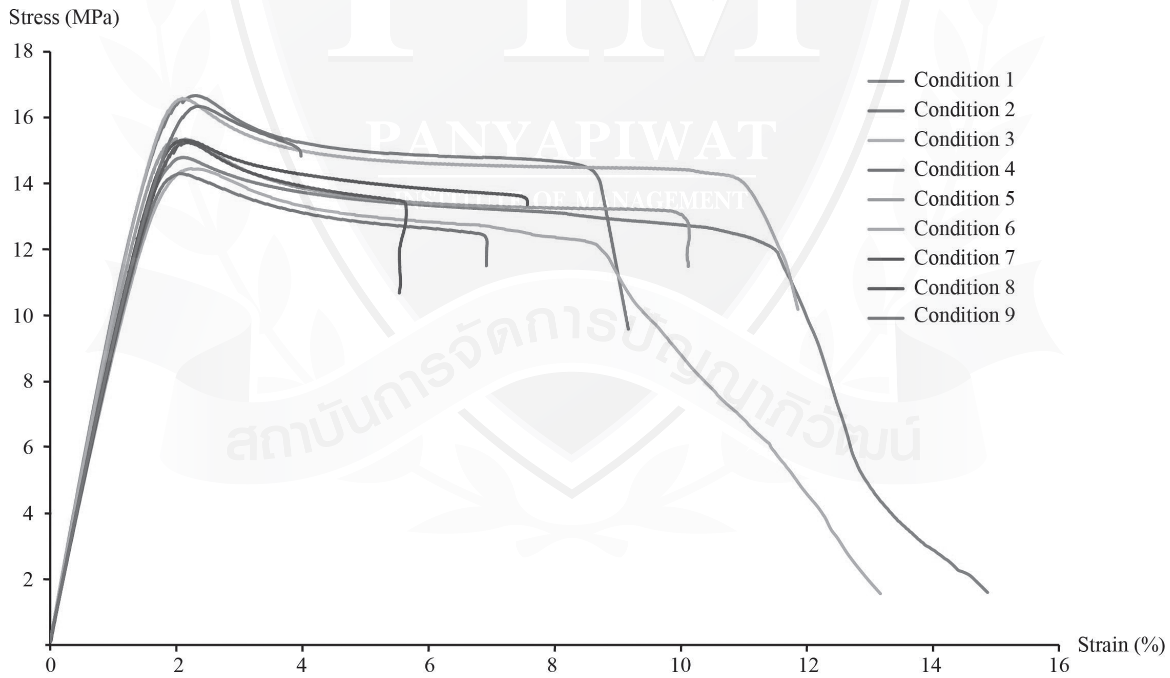

Fig. 4. Example of Stress-strain curve for specimens fabricated by each conditions in the first section of the experiment

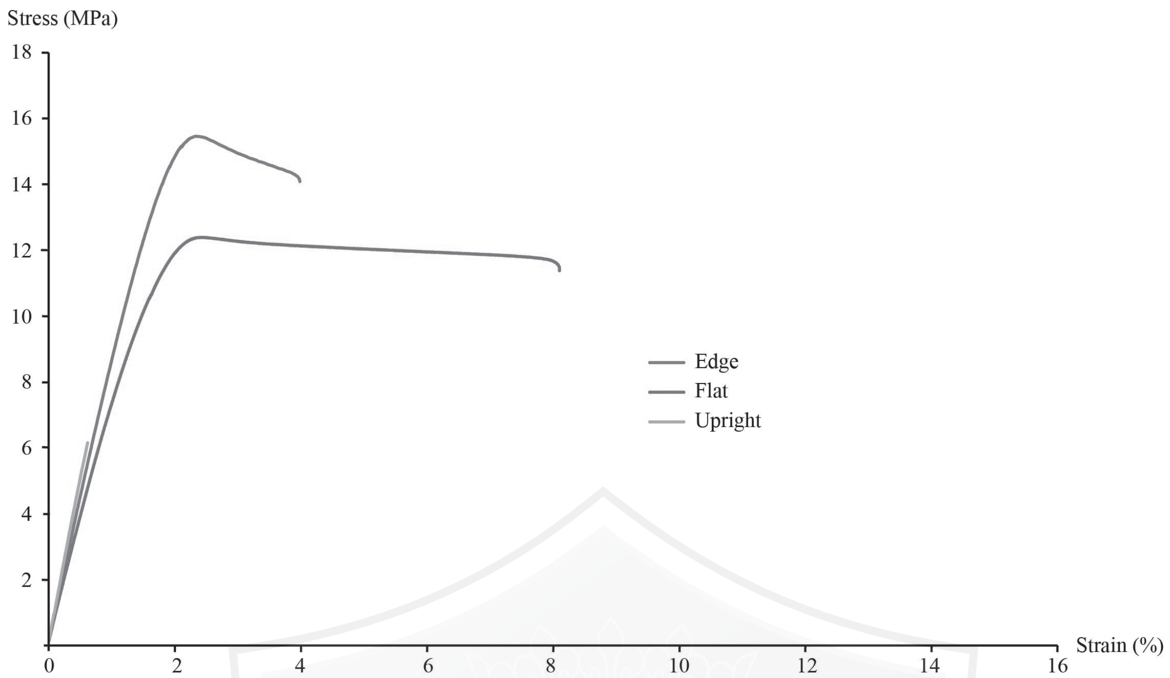

Fig. 5. Example of Stress-strain curve for specimens fabricated by different build orientation

In the first section of the experiment (Table IV), the result reveals that there is no difference in YS, UTS, elongation at YS and elongation at UTS in all conditions which ranged from 12.63-13.93 MPa, and 13.90-15.20 MPa, respectively. For the same layer thickness condition, values of ES depend on in-fill condition, the higher amount of in-fill leads, the greater ES, excepted for the condition 9 where the higher in-fill is not greater than condition 7 and 8. For the same in-fill condition, ES of the sample part fabricated using 0.09 and 0.19 mm layer thickness condition presents the lowest value of each in-fill group. In the low in-fill group, ES of 0.14 and 0.19 mm layer thickness is almost equivalent. The low, medium, and high in-fill group present the lowest ES observed in layer thickness of 0.19.

The second section of experiment (Table V) shows that the upright presents the highest ES, but the lowest YS, UTS, elongation at YS, and elongation at UTS. Sample fabricated in flat orientation presents the lower ES and YS values than edge orientation.

In addition to the numeric results, there is no obvious yield point in the stress-strain curve of upright specimens.

IV. Discussion

Mechanical properties play an important role for application of use. Newsday, FDM parts are not be only used as prototype, but it is used as products in many field, especially medicine. This is because the more biomaterials are available as alternatives, such as PLA and ABS. In product design process, it is crucial to understand the critical aspect of fabrication process which influences the strength. One of the applications use of FDM part has to be cautioned is the use as mechanical validation models for testing accuracy of numerical models, for example, CAE by means of finite element analysis (FEM).

From the results, it can be seen that mechanical properties of FDM part is anisotropy where the mechanical properties depends on direction of fabrication. This finding correlates with various previous studies who tested on different materials, for example the work of Bagsik et al. [14], Szykiedans et al. [10], and Ahn et al. [9].

In-fill is considered to be an influencer to mechanical property of FDM part, especially on ES. Although the value of YS and UTS has changed slightly over different in-fill conditions, but they still present greater values where higher in-fill is presented. The greater mechanical property can be explained simply by the more infill provides the more density to the part. The more part density reveals the more strength.

Layer thickness did not influence the mechanical properties as it is believed [15]. Generally, the smaller slice thickness presents the better mechanical properties. This may concern with selection of layer thickness interval used to FDM part fabrication in this study which is not different enough. Nevertheless, from this study, since the slice thickness presents no significant influence on mechanical strength, it had better to use the larger slice thickness of 0.19 mm to reduce the fabrication time. The fabrication time used for 0.09 mm slice thickness is twice to those use 0.19 mm slice thickness. Condition 3 presents high S.D. deviations of ES, this may be from the data collected on UTM in the elastic region, nevertheless, the S.D. of others mechanical properties is in low magnitude, the represented average values is still considered reliable.

Limitation of this study includes (1) the ability to change the in-fill direction in fabrication due to software version, (2) the tests is only in major axis (X, Y, and Z axis) orientations, (3) the batch test has not been performed to examine the reliability of fabrication process, and (4) the material is limited to ABS.

These limitation should be taken in to account in further study.

V. Conclusions

This study investigated the effect of FDM fabrication parameters, i.e. layer thickness and infill, and built orientation to mechanical property. Full factorial technique was used to determine the number of tested conditions. Tensile samples which had shape according to ASTM D638 fabricated with different fabrication conditions were used to test under tensile loading using UTM. The result was found that in-fill and built orientation are factors influenced the strength of the FDM part. Increasing of in-fill raises the strength of the part whereas the edge orientation presents the highest strength among others. Fabrication in upright orientation would make the FDM part more brittle. Interestingly, layer thickness presents a little effect on the mechanical properties of FDM part.

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System Dynamics Model for Estimating Water Pollution

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Abstract—**Water resources are essential for all living organisms. They are used for domestic consumption, agriculture, transportation, recreation, etc. Thus, water quality degradation is a global challenge, according to the United Nations (UN). This paper provides a system dynamics model that helps us see the interrelationships among water quality and the factors that affect it. The following are factors that influence the water quality in this model: national water policy, water and wastewater management, industrial growth, agricultural growth, population growth, and people's awareness of health. These factors are grouped the three main sectors: household, industrial, and agricultural. This system dynamics model helps to generate an overview of the problem and see how each factor affects each other. Thus, this model contributes to improving the quality of water.**

Index Terms—**System dynamics, Water pollution, Water quality, Water and wastewater management**

I. Introduction

The world in the 21st century has been facing many problems as a result of population growth [1, 2]. One of the major problems is the water quality problem, which continues to intensify. Approximately one-third of global biodiversity has been reduced as a consequence of intensifying water pollution problems [3-5]. In addition, water quality degradation has a direct impact on social, economic, and environmental quality [6, 7]. The problem of water pollution is worse in developing countries. Ninety percent of sewage in developing countries is directly discharged without treatment [8-10].

Water pollution is caused by many factors and comes from many sources. Sources of water pollution come from both point sources and non-point sources [5, 11, 12]. Most point sources' pollution is generated in the industrial sector [13]. UNESCO reports that industrial effluents are discharged into water bodies (approximately 300-400 megatonnes/year) around the world [5, 14]. Industrial wastewater has high hazardous chemical contamination, especially in metal finishing, electroplating, battery manufacturing, and chemical manufacturing industries [15-17]. For non-point sources, water pollution comes from agricultural and household sectors [7, 18]. For example, fertilizers and insecticides in the agricultural sector and household cleaning supplies in the household sector are products that can cause water pollution if discharged directly into water bodies [19]. Without proper wastewater and sewage treatments, these hazardous chemicals cause severe water pollution. Both point sources and non-point sources usually have a large amount of wastewater to release into water resources at a higher rate than a source's self-recovery capacity. This leads to persistently low water quality in water resources [20]. Due to the many factors that are involved in the deterioration of water quality, the need to understand an effective water quality system for water resources is important and desirable.

Recently, in order to reduce water pollution, water quality models, such as the Hydrological Simulation Program–FORTRAN (HSPF) [21], Watershed Analysis Risk Management Framework (WARMF) [22], and Soil and Water Assessment Tool (SWAT) [23], are widely used more than empirical methods [24-28] (e.g. differential analysis techniques, Fourier amplitude sensitivity test (FAST) [29]). The empirical models are constructed based on direct observations, measurements, and extensive data records [30]. They allow users to assess a variety of water resource allocation and management strategies. The empirical methods may not work properly on the deterioration of water quality problems because of nonlinearity, discontinuousness, intractability, and interaction of model parameters [31]. Some models, such as Morris Screening [32, 33] and General Sensitivity Analysis (GSA) [34, 35], are used to forecast water quality. However, these models can only provide qualitative predictions. Due to their mathematical complexity with a large number of parameters, these models often involve many uncertainties [36], especially when modeling water resource systems that have a lack of sufficient data for simulation and validation.

System Dynamics (SD), Discrete Event Simulation (DES), and Agent-Based Simulation (ABS) are methods that model complex systems. These methods have both advantages and disadvantages and are applicable in different situations. SD modeling is capable of analyzing complex systems, which have high abstraction, whereas DES modeling is used to analyze complex systems at low to medium abstraction [37]. ABS modeling is used for all levels of abstraction [37]. SD is able to model both continuous and discrete systems while DES and ABS are used in modeling discrete systems. An SD model is deterministic, but a DES model is stochastic in nature. An ABS model can be expanded from an SD model since all SD models have an equivalent formulation in an ABS model [38] . The outputs of ABS models show the complex behavior arising from individual decision-making [37, 39], while the SD models simplify an individual's decision making by aggregated entities in systems.

In this study, System Dynamics is used to describe the interrelationships of factors that influence the water quality in water resources. Many systems related to water resources are constructed using SD, such as water management systems, irrigation systems, and water quality systems [40-42]. Previous research on water quality systems was studied to improve water resource management. For instance, a water quality system was influenced by contaminated wastewater from wastewater treatment plants [42], and the Watershed System Dynamics model (WSD model) was developed to simulate population, land use, and runoff in the Nishi-Imbanuma basin, Chiba, Japan. The WSD model contained three sectors: agricultural sector, urban sector, and nature sector. These factors have interrelationships with water quality [43]. These studies did not directly study three social sectors: household, industrial, and agricultural sectors. Thus, this study differs from the previous studies as it applies the social interactions that have an influence on water quality. A Causal Loop Diagram (CLD) and a Stock and flow Diagram in SD are developed by using Vensim software, to show the interrelationships among different factors. This helps us to gain an understanding of the accumulation of water pollution.

II. Methods

System Dynamics models are used to model a water quality system in water resources. Since the main sources of water pollution in water resources are from household, industrial, and agricultural sectors, the SD model of a water quality system is composed of three subsystems, which include household, industrial, and agricultural subsystems [7, 44-46].

A causal loop diagram (CLD) is developed to show the interrelationships among causes and effects of factors that influence the water quality. A CLD consists of two components: variables and influences [47]. An influence has a direction represented by an arrow and an indicator that indicates a change of two variables. If two variables change in the same direction, then the indicator is represented by +. If two variables change in the opposite direction, then the indicator is represented by -. Another important notation is used to represent feedback loops. There are two main types of feedback loops. A balancing feedback loop (B loop) preserves the level of variables. For example, an increase in death rate reduces the population number, while an increase in population number increases the death rate, as shown in Fig. 1. The second type of feedback loop is a reinforcement loop (R loop) which is a loop that continuously increases or decreases the level of variables. As shown in Fig. 1, the population number increases (decreases) as the birth rate increases (decreases) since an increase (decrease) in population leads to an increase (decrease) in the birth rate. The population number depends on the types of feedback loops. Types of feedback loops usually determine the main behavior of a system [47].

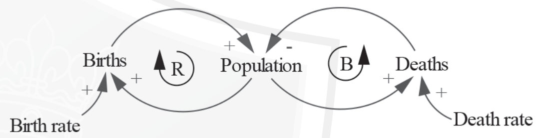

Fig. 1. Simple causal loop diagram of population growth

A stock and flow diagram is another useful model in SD. A fundamental component of a stock and flow diagram is stock, which is the level or condition of a measurable element at a point in time. Stocks are entities that can accumulate or deplete. A level of stock changes with the flows associated with the stock [48-50], as shown in Fig. 2. The population number is regarded as a stock. The population number increases when the inflow of births is higher than the outflow of deaths. However, the stock of population decreases when the inflow of births is less than the outflow of deaths.

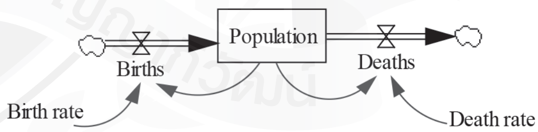

Fig. 2. Simple stock and flow diagram of population growth

III. Result and Discussion

Household Subsystem

Population growth leads to urban expansion and increases in food and water demand [51]. Wastewater and solid waste increase as a result of an increase in food and water demand [52]. Discharging untreated wastewater and solid waste into water resources leads to declining water quality. When water quality is degraded, people who live near water resources are affected by water pollution. As a consequence, these people become aware of water pollution [53, 54]. They are willing to restore water quality to have good water conditions around them for their consumption and other activities. When people have awareness of health, they are willing to follow government policies by reducing the discharge of wastewater and solid waste into water resources. Furthermore, people's awareness of health can influence the government to change policies, to increase wastewater treatment efficiency and improve solid waste disposal management. These policies can help to improve water quality. Fig. 3 shows the interrelationships between water quality and household consumption.

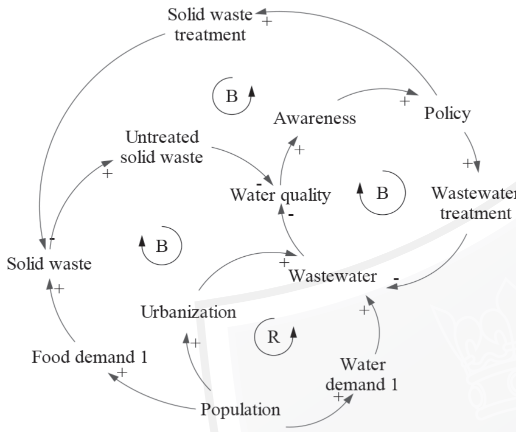

Fig. 3. CLD of water quality affected by household sector

Industrial Subsystem

Interrelationships between industry and water quality are described in Fig. 4. Population growth has resulted in economic expansion and industrial development to respond to human needs [55]. Consequently, higher production is necessary to support these needs. Most production processes use a large amount of water, which also means that they produce a large amount of wastewater. Some untreated wastewater is directly discharged into a water body and degrades water quality [56-59]. For example, aqueous wastes from the semiconductor electronics industry is the main source of chromium, nickel, cadmium, etc. in surface water [60]. As water resources are contaminated, industries and residents near a water resource are affected. They are aware of water pollution. Thus, they are interested in improving water quality [53]. This leads to public and private organizations cooperating to urge the national government to improve water resources.

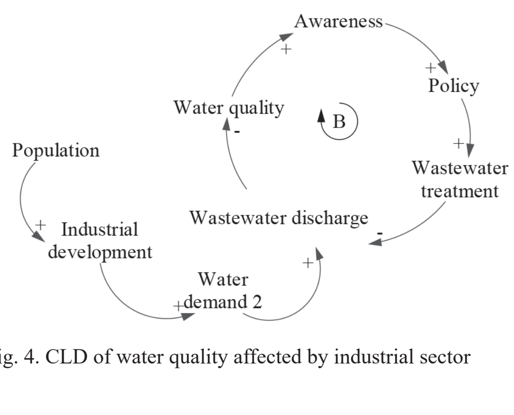

Fig. 4. CLD of water quality affected by industrial sector

Agricultural Subsystem

The increase in population has resulted in higher food consumption. Thus, an agricultural sector is required to fulfill this need [59, 61]. As the rate of cultivation increases, the amount of water used in agricultural processes also increases. As a result, the amount of wastewater from the agricultural sector increases. If untreated wastewater flows into water resources, then water quality degradation occurs. Fertilizers and chemicals that are used in agriculture mainly consist of organic matter [62]. If these components are overused on farms, then the unused amount of nutrients and organic matter are washed into water resources [45]. This leads to eutrophication which causes low water quality in water resources [20, 63]. When water quality is degraded, farmers cannot use water from water resources for their farms. Thus, farmers are aware of the problem and turn their attention to water quality problems [53, 54]. Farmers can be a driving force to require new policies to reduce fertilizers and chemical usage in cultivation. In addition, new policies to reduce wastewater and reuse water in plantations are encouraged. Fig. 5 demonstrates the interrelationships between water quality and agriculture.

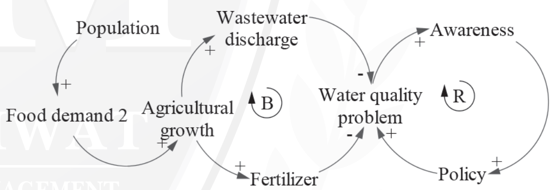

Fig. 5. CLD of water quality affected by agricultural sector

The interrelationships of the three subsystems can be summarized in Fig. 6. An increase in population results in urbanization and an increase in water and food demand, which are followed by an agricultural and economic expansion. In the process of cultivation and production, a large amount of water is used from water resources. As a result, a large amount of wastewater, solid waste, and leftover fertilizer are generated. Subsequently, water quality is degraded. The interrelationships of the three subsystems mentioned above show that those people who are affected by water pollution both directly and indirectly are more interested in and aware of the water pollution problems. When the people's awareness increases, people start to follow the national water policies. Also, they avoid releasing wastewater and dumping solid waste into water resources. These actions can eventually improve water quality.

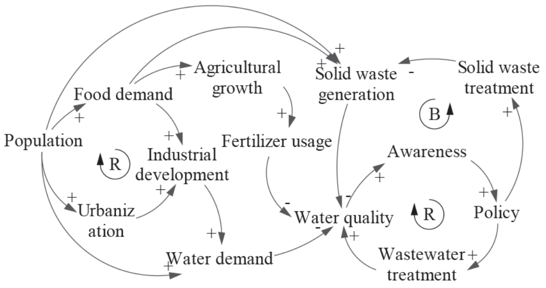

Fig. 6. CLD of water quality in a water resource

After perceiving the interrelationships of the three subsystems in the CLDs, a stock and flow diagram is created. To present the levels and flows of variables that are interrelated to water quality, a stock and flow diagram of a water quality system is presented in Fig. 7. The water pollution problem is intensified due to the influence of the volume of untreated wastewater and untreated solid waste in water resources. A factor that affects the amount of wastewater and solid waste is the population growth. The amount of wastewater discharge is also affected by industrial development and agricultural growth. To reduce the volume of wastewater, the water consumption and solid waste generation rate should be reduced. Increasing the capacity of wastewater treatment and solid waste treatment plants can reduce the amount of untreated wastewater and solid waste, respectively. Moreover, people's awareness of health is another factor that can indirectly reduce wastewater discharge and solid waste generation.

An example of a simulation run of the total water pollution generation for the next ten years in the world is shown in this paper. The equations that are used in the model are linear equations. The parameters in this model are from a literature review and assumptions. Table I shows all of the functions that were used in the model. Water consumption (WC) is calculated from the rate of water consumption (56,575 L/capita/year) [64]. Food demand (FD) is generated from the food consumption rate (334 Kg/capita/year) [65]. Agricultural growth (AG) and industrial development (IN) are generated from the percentage of GDP reported by the world bank [66]. For the functions of wastewater from farms (WF) and from industries (WI), we assume that an increase of 1% of GDP leads to a 50,000 L increase of wastewater. The awareness function is created by assuming that if the water pollution (WP) is lower than 5×10^{14} L, the awareness value is 0 (no awareness). Otherwise, the awareness value is 1 (awareness). The function of wastewater discharge (WD) is correlated with the awareness function. If the awareness value is 1, then people discharge only 80% of the wastewater, which is from the wastewater from consumption (WC), wastewater from farms (WF), and wastewater from industries (WI).

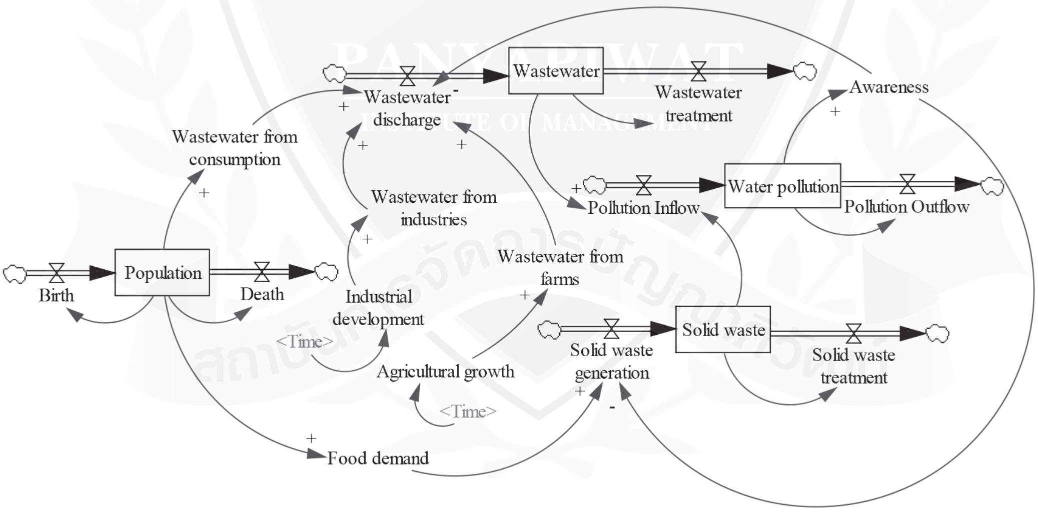

Fig. 7. Stock and flow diagram of water quality in a water resource

Otherwise, people discharge all of the wastewater. Solid waste generation (SG) is also correlated with people's awareness. If the awareness value is 1, then people dispose of 50% of the solid waste generation. However, if people do not have awareness, then they dispose of all of the solid waste generation. Pollution inflow (PI) is a combination of the water pollution occurring from wastewater and solid waste. The pollution of water occurring from solid waste is assumed to be 20% of the untreated solid waste. The population number (Pop), volume of wastewater (WW), volume of solid waste (SW), and total water pollution (WP) are stocks which are created by accumulating the difference between the inflow and the outflow of each stock. Initial values and rates that are used in this simulation are shown in Table II. Two important factors that affect water pollution are the efficiency of solid waste treatment plants (SWT) and the efficiency of wastewater treatment plants (WWT).

TABLE I
DESCRIPTIONS OF
VARIABLES AND UNITS USED IN THE SIMULATION.

Variables	Equations	Units
WC	56,575×Pop	L
FD	334×Pop	Kg
AG	-0.0281×Time + 4.1016	%
IN	-0.1703×Time + 17.97	%
WF	50000×AG	L
WI	50000×IN	L
Awareness	IF THEN ELSE (WP<5×1014, 0, 1)	-
WD	IF THEN ELSE (Awareness=1, 0.5×(WC+WF+WI), (WF + WI + WC))	L
SG	IF THEN ELSE (Awareness=1, 0.5×((FD/334)×533), (FD/334)×533)	Kg
PI	WW+0.2×SW	L
Pop	$\int_0^{10} Births - Deaths \quad dt$	People
WW	$\int_0^{10} WD - WT \quad dt$	L
SW	$\int_0^{10} SG - SWT \quad dt$	Kg
WP	$\int_0^{10} PI - Pollution \quad Outflow \quad dt$	L

TABLE II
Parameters Used in the Simulation: Initial Values, Units, and Sources of Parameters.

Variables	Initial values/Rate	Units	Sources
Pop	7.6×109	People	[68]
Births	18	People/1000	[69]
Deaths	8	People/1000	[69]
WW	4.57×1014	L	Assume
SW	5×1012	Kg	Assume
WWT	20	%	[70]
SWT	77	%	[71]
WP	5×1014	L	Assume

Fig. 8 shows the result from the model, which is a prototype of a system dynamics model. The trend of the amount of WP on the Earth is demonstrated from 2018 to 2028, and the trend is gradually increasing. The result demonstrates the potential of the developed system dynamics model to generate the trend of accumulated pollution in water resources. However, this simulated result cannot provide an accurate forecast of the trend of wastewater in the world due to a lack of data. This model can be used as a guideline to develop a model to forecast the trend of water pollution in the future.

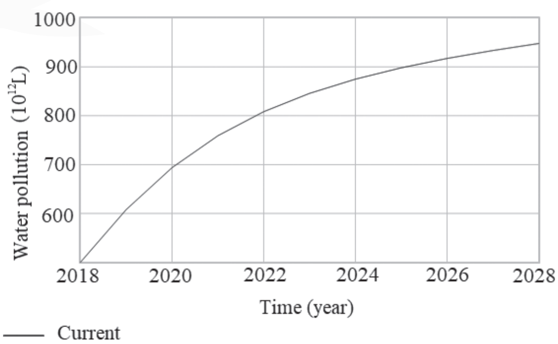

Fig. 8. Result from the simulation that shows the amount of wastewater in the world from 2018 to 2028.

IV. Conclusion

This study explores the interrelationships of factors that influence the water quality in water resources by using a System Dynamics (SD) approach. The SD model is composed of three subsystems, including the household, industrial, and agricultural sectors. In this paper, the result shows that the SD model can track the trend of water pollution in a water resource. Thus, this SD model can be used as a guideline for studying water quality at specific water resources. This model leads to a better comprehension of the interrelationships among the users and the health of a water resource. In the future, the SD model can be applied to track water pollution, such as nitrogen and phosphorus. In addition, alternative public policies, such as improving wastewater treatment, solid waste disposal, and raising people's awareness, can be evaluated in the model, to achieve environmental sustainability in water resources.

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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.

<u>Basic format for standards:</u>

[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.

The second paragraph uses the pronoun of the person (he or she) and not the author's last name. It lists military and work experience, including summer and fellowship jobs. Job titles are capitalized. The current job must have a location; previous positions may be listed without one. Information concerning previous publications may be included. Try not to list more than three books or published articles. The format for listing publishers of a book within the biography is: title of book (city, state: publisher name, year) similar to a reference. Current and previous research interests end the paragraph.

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.

Second B. Author was born in Greenwich Village, New York City, in 1977. He received the B.S. and M.S. degrees in aerospace engineering from the University of Virginia, Charlottesville, in 2001 and the Ph.D. degree in mechanical engineering from Drexel University, Philadelphia, PA, in 2008. From 2001 to 2004, he was a Research Assistant with the Princeton Plasma Physics Laboratory. Since 2009, he has been an Assistant Professor with the Mechanical Engineering Department, Texas A&M University, College Station. He is the author of three books, more than 150 articles, and more than 70 inventions. His research interests include high-pressure and high-density nonthermal plasma discharge processes and applications, microscale plasma discharges, discharges in liquids, spectroscopic diagnostics, plasma propulsion, and innovation plasma applications. He is an Associate Editor of the journal *Earth*, *Moon*, *Planets*, and holds two patents.

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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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