FINAL PROJECT – TI141501

FLY ASH ALLOCATION PROBLEM USING NORMALIZED WEIGHT GOAL PROGRAMMING

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DEPARTMENT OF INDUSTRIAL ENGINEERING
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APPROVAL SHEET

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FINAL PROJECT

Proposed as a Requisite to Graduate in Indutrial Engineering Major and to
Achieve a Bachelor Degree in Department of Industrial Engineering
Faculty of Industrial Technology
Institut Teknologi Sepuluh Nopember
Surabaya

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ABSTRACT

In order to produce electricity Coal based Power Plant combust certain amount of coal inside the furnace. Besides producing electricity, this combustion process leaves some kind of residue called fly ash and bottom ash. Currently, Coal Power Plant owned by PLN, a state owned company, manages this residue by having them buried inside plant area. This action turns out to be a violation against the Government Regulation. This research tries to help PLN to map the potential usage of the fly ash and decide the best allocation so that the cost is minimized and the value is maximized. Therefore goal programming is employed to solve this problem. Before the allocation is done, fly ash is classified into several class to determine the potential usage because each requires different chemical composition. In this research the usage is limited into 3 potential, cement, geopolymer, and landfill. Since fly ash is included as Toxic and Hazardous Substance, a long distance transport is not economical due to higher cost to load dangerous materials. Therefore, the Power Plants are grouped into several clusters. Then, the potential users in each cluster are searched. From the result of calculation in 6 scenarios, there are around 38% to 54% of fly ashes allocated for the usage in cement industry, between 27% to 32% of fly ash for geopolymer product, and around 19% to 30% for landfill. The transportation cost to ship the fly ash to potential user is ranging from 87 billion to 146 billion Rupiah. It is found that the cost to transport fly ash for landfill usage contributes to half of the total cost even though the volume that is delivered is low. The reason is a lot of fly ash from Power Plant only can be used for landfill while the landfill location is far away across islands.

Keywords: allocation, fly ash, goal programming, multi-objective, optimization

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PREFACE

Praise the Mighty Lord, Allah SWT, for His Blessing and Guidance, in helping the author to successfully accomplish this research for final project titled "Multi-objective Optimization of Fly Ash Allocation Problem in PLTU Using Normalized Weight Goal Programming" on time. This final project is composed as one of the requisite to achieve a Bachelor degree in Industrial Engineering Department, Institut Teknologi Sepuluh Nopember. In finishing this final project, author had received a lot of help, support, and motivation from many parties. Therefore, in this occasion, author would like to say thank you for those who had been involved in supporting the completion of this final project. Those are:

1. Prof. Ir. I Nyoman Pujawan, M.Eng, Ph.D, CSCP as author's supervisor for this final project who had given a great suggestion, supervision, and motivation to the author.
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6. The author's beloved parents, brother, and sister, for all their affection, prayer, and great support both moral and material.
7. Others parties who had supported the author in finishing the final project, who can't be mentioned one by one.

The author realizes that this research is far from perfection. Nevertheless, the author expects constructive recommendation and critics regarding to the shortcoming in this final project so that it can be improved. Hopefully this report can bring benefits and contribution in enriching the knowledge of the readers.

Surabaya, 8 January 2017

Gery Alfian Ilham Radika

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CHAPTER 1
INTRODUCTION

In this chapter will be discussed the introduction regarding to this Final Project. The introduction will include the background of this Final Project, problem formulation, objectives, benefits, scope that consists of limitations and assumptions, and the systematic report outline for this Final Project.

1.1 Background

PLN stands *for Perusahaan Listrik Negara* is a state-owned company that act as electricity power provider and distributor in Indonesia. In order to provide the electricity supply, PLN has many Power Plants spread throughout Indonesia archipelago. Some electricity supply is also provided from Private-owned Power Plant. There are many types of Power Plants that operate in Indonesia authority such as Steam Power Plant, Hydro Power Plant, Gas Power Plant, and etc. According to BPS data, Coal-based Steam Power Plant or PLTU has the highest growth rate in terms of installed capacity. The total installed capacity of all PLTU were increased from 8764 MW in 2009 to become 29931.9 MW in 2015 (Badan Pusat Statistik, 2016). Comparing to other major type of Power Plant, installed capacity growth on PLTU is 20000 MW higher. In 2015, the total installed capacity of all Power Plant in Indonesia reached 55 GW. This means PLTU contributes to more than 50% of Indonesia's electricity supply.

In order to generate electricity, PLTU burns coal to create steam that moves generator. Combustion of the coal will leave residue called as Fly Ash and Bottom Ash or FABA. Based on Government Regulation No 101/2014 FABA is categorized as Toxic and Hazardous Substance that needs to be handled with specific action. FABA is considered as Toxic and Hazardous Substance as there is potential where this residue can cause soil and water pollution from metal leaching. Metal leaching is significantly occurred for acid material, but in fact, most of FABA is alkali (Dunia Energi, 2016). Otherwise, FABA is more appropriate to be categorized as ordinary waste according to Mr. Budi Santoso, Executive Director of Center for Indonesia Resources Studies (Dunia Energi, 2016).

As the program for providing 35000 MW additional electricity power in Indonesia was launched, more Power Plant needs to be built. By looking from the statistics data and this program, there is great potential that it would increase the production of FABA. It is estimated that production of FABA in Java Island itself will reach 11.18 million ton per month in 2027, a combination from PLN with 6.5 million ton and IPP 4.6 million ton (Dunia Energi, 2016). Currently, FABA produced by PLTU is usually hoarded or used by industry as mixture for other product such as cement and concrete. The majority usage of FABA itself is from the Fly Ash, while Bottom Ash is still rarely used. In fact the spread of FABA usage is not evenly distributed, only in certain area especially in Java. In other islands outside Java, FABA is relatively be hoarded instead of absorbed by other industries. The absorption of FABA in Java is carried out by 4 major companies, Holcim, Semen Gresik, Indocement, and Wika Beton (Katharina & Felani, 2017). Moreover, the rate of absorption for other industry to create product is not proportional to the FABA production itself. The total absorption of FABA for cement and concrete from 2012-2027 is approximated to reach 7.16 million ton, while 15.36 million ton will still be hoarded (Dunia Energi, 2016). For PLN, this accumulation of FABA considered as additional cost that makes the operational of their PLTU becomes less effective.

Several alternative for FABA usage needs to be sought besides the existing method. The existence of more cements plants that are currently being built in Indonesia becomes one of the opportunity to increase the usage of FABA, more specifically the Fly Ash. Mapping the potential user of Fly Ash for cement and concrete industries in Indonesia can provide a better insight on how much the absorption could made. Other innovative usage of FABA is as road base and landfill (American Coal Ash Association, 2003). Unfortunately, there is still no regulation that manage the usage of FABA as this alternative product. To help PLN solves this problem, an optimization model could be created to decide the allocation of Fly Ash that should be made by each PLTU for certain product on certain industry so that it minimizes the total cost of shipment as well as maximizes the total value from fly ash shipped.

Obviously there are two objectives that wants to be achieved by PLN as the owner of the problem. This type of optimization problem is known as multi-objective optimization problem or MOOP (Santosa & Willy, 2011). In MOOP, these objectives may conflict to each other. The cost minimization of fly ash distribution may result in worse objective function in generating maximum value and vice versa. There are many methods in solving MOOP. Here goal programming is used to solve the multi-objective allocation problem. The terms goal programming is first introduced in 1961 by Charnes and Cooper (Tamiz & Jones, 1996). In multi-objective goal programming, it is known for the term hard constraint and soft constraint. The hard constraint is the constraint that cannot be violated while achieving the objective function. In the other hand, soft constraints gives tolerance to achieve the optimum multi-objective solution to tackle the conflict among the objectives. Here, in goal programming such tolerance, or called as deviation, is tried to be minimized. In this problem, the deviations from the minimum total cost and maximum value are minimized so that the optimum total objective function is achieved. Generally there are 2 methods in goal programming, the first method is based on weight assigned to each objective, and the second method is based on priority level of the objective. To solve fly ash allocation problem, the first method or known as Weighted Goal Programming (WGP). By using WGP, the objective function in minimizing the deviation from total cost and total value will be normalized in order to eliminate incommensurability due to different unit of measurement from both objectives.

1.2 Problem Formulation

Based on the background explained before, this study addresses the allocation of fly ash from each PLTU to potential users so that the solution minimizes transportation cost and maximizes values obtained from the usage of fly ash.

1.3 Objectives of Research

The objectives of conducting this research are:

1. To obtain map of fly ash productions and usage.
2. To maximize the usage of fly ash for the appropriate industry in a cost effective way.

1.4 Benefits of Research

The benefits of conducting this research are:

1. The result of this research can be used to provide solution for PLN to solve Fly Ash allocation problem for their PLTU.
2. The multi objective algorithm that is produced can be modified whenever new potential or alternatives usage of FABA are found.

1.5 Scope

In this subchapter will be explained the scope of this research that includes the limitations and assumptions.

1.5.1 Limitations

The limitations used in this research are:

1. PLTU that are evaluated are those owned by PLN.
2. Only fly ash that is evaluated for the allocation problem.
3. Only usage for concrete, cement, and landfill are considered in this research.

1.5.2 Assumption

The assumptions used in this research are:

1. The capacity of shipment is assumed to be 20, 30, and 45 ton.
2. The road infrastructure is sufficient to support the truck with capacity up to 45 ton.
3. Fly ash usage for mixture in cement, geopolymer, and landfill is not harmful.
4. Only direct shipment is considered.

CHAPTER 2
LITERATURE REVIEW

This chapter will mainly explain and discuss about the literature review related to this Final Project. In here will be introduced the theory and concept of fly ash and bottom ash, the characteristics of fly ash, potential usage of fly ash, physical distribution and transportation, multi-objective optimization problem, and goal programming. The literature review will be used as the reference for data processing as well as optimization modelling.

2.1 Fly Ash and Bottom Ash

Fly ash and bottom ash or FABA are solid materials left from the combustion of pulverized coal from coal-based Power Plant. According to Mrs. Januarty, a lecturer from Civil Engineering Department, ITS, from the combustion of pulverized coal, fly ash will contributes to around 80 to 90 percent of the total ash produced, which means that bottom ash is only 10 to 20 percent. These 2 types of ash come in grey color with different particle size. Fly ash is a fine-grained powdery materials that is carried out in the flue gas and captured by electrostatic precipitators (American Coal Ash Association, 2003). This ash contains inorganic materials from the combustion of the coal. Solidification happens as it is suspended in the flue gas tube. As the result, fly ash particles are mostly spherical and vary in diameter. If these particles closely observed under microscope, they will look like solidified bubbles. In average, fly ash particle's size is around 10 μm (Ramme & Tharaniyil, 2013). The main compositions of this ash are Silicon Dioxide (SiO_2), Aluminum Oxide (Al_2O_3), and Ferro Oxide (Fe_2O_3) (Ramme & Tharaniyil, 2013).

On the other hand, bottom ash particles are much coarser that fly ash. The size ranges from approximately as small as fine sand to the size of pebble. Bottom ash is also produced from the combustion of pulverized coal. The difference from the fly ash is that this residue is left in the bottom of the combustion chamber or furnace (American Coal Ash Association, 2003)**.**Other than the size and the location where it is found, bottom ash is typically quite similar to fly ash. The chemical composition is similar to that of fly ash, but only with greater amount of carbon in it.

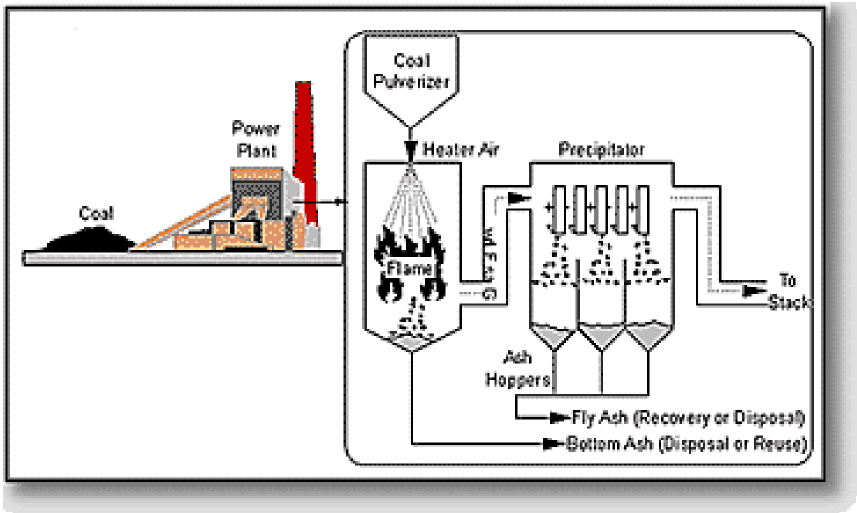

Figure 2. 1 Fly Ash and Bottom Ash Production
(American Coal Ash Association, 2003)

The production of fly ash and bottom ash will continuously increase along with the increase on coal-based power plant in Indonesia (Badan Pusat Statistik, 2016). Currently, these residues are mostly be hoarded and kept somewhere in the power plant area. Only a small number of power plants have already sold them to be used by other industry, particularly the fly ash. The accumulation of fly ash and bottom ash could create environmental problems such as soil, and water pollution that needs to be prevented through the usage for other industry such as cement or concrete.

2.2 Fly Ash and Bottom Ash Characteristics

Fly ash and bottom ash can be classified into several categories based on the constituent materials or characteristics. These characteristics are built up from the type of coal used, the type and condition of furnace, and temperature during combustion. Here are the common chemical composition in the ash that is produced from different type of coal.

Table 2.1 Fly Ash Chemical Composition from Different Type of Coal

Compounds	Symbol	Type of Coal		
		Bituminous	Sub-bituminous	Lignite
Silicon Dioxide	SiO_2	20-60	40-60	15-45
Aluminum Oxide	Al_2O_3	5-35	20-30	10-25
Iron Oxide	Fe_2O_3	10-40	4-10	4-15
Calcium Oxide	CaO	1-12	5-30	15-40
Magnesium Oxide	MgO	0-5	1-6	3-10
Sulfur Trioxide	SO_3	0-4	0-2	0-10
Sodium Oxide	Na_2O	0-44	0-2	0-6
Potassium Oxide	K_2O	0-3	0-4	0-4
Loss on Ignition	LOI	0-15	0-3	0-5

(Ramme & Tharaniyil, 2013)

Table 2.2 Bottom Ash Chemical Composition from Different Type of Coal

Compounds	Symbol	Type of Coal	
		Bituminous	Sub-bituminous
Silicon Dioxide	SiO_2	61	46.7
Aluminum Oxide	Al_2O_3	25.4	18.8
Iron Oxide	Fe_2O_3	6.6	5.9
Calcium Oxide	CaO	1.5	17.8
Magnesium Oxide	MgO	1	4
Sodium Oxide	Na_2O	0.9	1.3
Potassium Oxide	K_2O	0.2	0.3

(Ramme & Tharaniyil, 2013)

ASTM C618 (American Society for Testing and Materials) about Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, has 2 classes for fly ash classification which are Class F and Class C. These classes differentiate fly ash based on its origin and composition. Class F ashes are generally produced from the combustion of bituminous and anthracite coals (Ramme & Tharaniyil, 2013). In order to be classified in F Class, the ash should at least contains more than 70 percent of combination from Silicon Dioxide, Aluminum Oxide, and Iron Oxide in its chemical compound (Thomas, 2007). In another hand the type C ashes are normally derived from the combustion of sub-bituminous or lignite coal. Slightly different from Class F, Class C chemical composition should at least contains 50 percent of combination from Silicon

Dioxide, Aluminum Oxide, and Iron Oxide but less than 70 percent or otherwise it will be included as Class F (Thomas, 2007). In addition, ASTM C618 also defines the third class of mineral admixture which is Class N. This class mineral compounds are natural pozzolans such as diatomaceous earths, opaline cherts and shales, volcanic ashes or pumicities, calcined or uncalcined, and other materials that need calcination to gain cementious properties, such as shales and clays (American Coal Ash Association, 2003)**.** Although ASTM C618 does not differentiate the content of Calcium Oxide (CaO) between Class F and Class C, but typically Class F contains 5 to 10 percent of CaO and Class C contains 15 to 20 percent of CaO. For that reason, Class F is also known as low calcium ash while Class C is high calcium ash. For more complete class classification, here is the table of ashes classification.

Table 2.3 Fly Ash Classification ASTM C618

Compounds	**Symbol**	**Ash Classes**	
		Class F	**Class C**
Silicon Dioxide	SiO_2	70%	50%
Aluminum Oxide	Al_2O_3		
Iron Oxide	Fe_2O_3		
Calcium Oxide (Lime)	CaO	9%	24%
Magnesium Oxide	MgO	2%	5%
Sulfur Trioxide	SO_3	1-5 %	3-5 %
Loss on Ignition	LOI	6% (max)	6% (max)
Moisture Content	-	3% (max)	3% (max)
Available Alkali as Equivalent Na_2O	-	1.5% (max)	1.5% (max)

(Ramme & Tharaniyil, 2013)

Beside ASTM C618, there is also CSA A3001 which is the specification of fly ash issued by Canadian authority. The CSA A3001 which is about *Cementitious Materials for Used in Concrete* classifies fly ash into three categories based on the calcium content (Thomas, 2007)**.** The calcium content in fly ash gives the indicator on how it will behave as it is mixed to create concrete. Calcium inside the fly ash, when it is mixed with water, will react and harden due to the formation of cementitious hydration products (Thomas, 2007). Furthermore, calcium content is also useful to predict the effectiveness of fly ash in reducing hydration heat (Thomas, et al., 1995), control the expansion due to alkali-silica reaction (Thomas & Shehata, 2000), and give protection against sulfate (Thomas & Shashiprakash, 2001).

The 3 classes of fly ash based on CSA A3001 are Type F, Type CI, and Type CH. Type F is the class with the lowest calcium content in it. Fly ash should contain less than 8 percent of Calcium Oxide (CaO) to be included in this class. Type CI contains a middle range of calcium content, which is ranging from 8 to 20 percent of CaO chemical composition. Fly ash that is included in the last class, Type CH, has high calcium content within the chemical compound around 20 percent and more. Below is the table of CSA A3001 for fly ash classification.

Table 2.4 Fly Ash Classification CSA A3001

Type	**Calcium Content (CaO)**
Type F	< 8%
Type CI	8 - 20 %
Type CH	> 20 %

(Thomas, 2007)

All fly ashes that are already met the CSA classification can be categorized as either Class F or Class C by ASTM C618. Type F in CSA could be included as Class F in ASTM, and Type CH is categorized as Class C. However, for type CI could be classified as either Class C based on the coal source or Class F based on the sum of Silicon, Aluminum, and Iron Oxide (Thomas, 2007). Based on ASTM C618 table, it is known that the sulfate content (SO_3) is limited to maximum 5 percent for both classes to be used in concrete. CSA A3001 also applies such a limit but also allows the limit to be exceeded as long as it is proven from the test that the fly ash does not produce deleterious expansion (Thomas, 2007).

Both ASTM C618 and CSA A3001 is also placed a limitation of loss-on-ignition (LOI) to the composition of fly ash to be used in concrete. ASTM C618 limits the LOI up to 6 percent both for Class F and Class C, while CSA A3001 limits the LOI up to 8 percent for Type F and up to 6 percent for Types CI and CH fly ashes (Thomas, 2007). LOI is a measurement for the residual unburned carbon (coal) remaining in the ash (American Coal Ash Association, 2003). The high carbon level can adversely affect the durability of concrete. Therefore a low and consistent LOI is desired to minimize chemical admixtures used and produce durable concrete. The carbon within the fly ash could come from the additional activated carbon added to the power plant air quality control systems to remove mercury from combustion gases. Carbon particles can bring up 2 issues when it is used as cementitious materials in concrete. The carbon has high affinity for air entraining admixtures, so that it is difficult to predict the air content in concrete. Carbon could also give darker color or black surface speckles and it compromises the aesthetic aspect on concrete (Ramme & Tharaniyil, 2013).

In addition to the characterization from the chemical components, the color of ashes also gives certain meaning. Fly ash with tan and light colors typically contains high lime or calcium constituent. A brown color can indicate more iron content within the fly ash. The darker color, gray to black, is typically attributed to an elevated unburned carbon (American Coal Ash Association, 2003). The color of fly ash is determined by the coal source and type of boiler in the power plant, and tend to be consistent. Another important fly ash parameter or characteristics is fineness. Fineness is closely related to the operating condition of coal crusher and coal's grind ability (American Coal Ash Association, 2003). Coarser ground coal could result a higher percentage of unburned residues which will cause high LOI. Moreover a coarser gradation on fly ash makes the ash less reactive due to less contact to particle surface. To improve the fineness of fly ash, the ash can be processed by screening or air classification (American Coal Ash Association, 2003).

Uniformity is also important thing to consider for fly ash usage in most application. Based on the Unified Soil Classifications System, fly ash particles are in between the range of clay particle size to sand particle size. For geotechnical application, fly ash is usually classified as silty sand (Ramme & Tharaniyil, 2013). The geotechnical engineering properties of fly ash are useful when it is designed for use in application of backfilling the wall or embankments construction (Ramme & Tharaniyil, 2013). Here is the typical geotechnical properties of fly ash.

Table 2.5 Fly Ash Geotechnical Properties

Testing Descriptions	Results
Internal Friction Angle (10)	26° - 42°
Initial Stress-Stain Modules (triaxle test) (9)	30 MPa
Stress-Stain Modules (plate load tests) (9)	100 MPa
Modules of Subgrade Reactions (300 mm diameter plates [Ks]) (9)	130 KPa/mm
California Bearing Ratio, Un-soaked (Low Lime Fly Ash) (11)	10.8-15.4
California Bearing Ratio, Soaked (Low Lime Fly Ash) (11)	6.8-13.5
Cohesion*	0
Permeability (10)	10^{-4} cm/sec –
	10^{-6} cm/sec
Maximum Dry Density (60-110 lb. /cu ft.) (10)	960-1760 kg/m3

(Ramme & Tharaniyil, 2013)

2.3 Fly Ash Potential Usage

Application of fly ash for many products in other industry is quite various. Fly ash can be used in Portland Cement Concrete, stabilized base course, soil improvement, asphalt pavements, and grouts for pavement sub-sealing (American Coal Ash Association, 2003). There are a lot of benefits that can be obtained from the use of fly ash for certain criteria in certain product. But there are also cautions need to be noticed in order to get the maximum benefit.

2.3.1 Fly Ash in Cement and Concrete

Fly ash for concrete admixtures can enhance the performance of the concrete. Lime inside the fly ash will produce cementitious properties when it is exposed certain chemical reaction, with water for example. This fly ash for concrete has already been used for some highway and construction and proven to give many benefits. Fly ash may be used both for fresh concrete and hardened concrete. In fresh concrete, the usage of fly ash could reduce the water requirement for mixing. As much as 20 percent of total cementitious properties in concrete if replaced by fly ash will reduce water demand by 10 percent (American Coal Ash Association, 2003). The shape of fly ash which is mainly spherical can act like a lubricant. Therefore it will improve the concrete pump-ability as it reduces the friction during pumping process. Heat of hydration on fresh concrete can also be reduced that directly will lessen heat rise problems in mass concrete placement. In application for hardened concrete, fly ash could produce extra strength as oppose to ordinary concrete. Less water content that is needed also improve the reduction on pore interconnectivity which then decrease the permeability and increase long-term durability. The fly ash application for concrete has been regulated under European Standard EN 450-1. The composition of this standard is similar to the Class F specification under ASTM C168, but with more additional restriction.

Cement is also another product that can be improved through fly ash usage. Fly ash can be used for all types of cements: Portland cement, performance cement, and blended cement (American Coal Ash Association, 2003) . For blended or pozzolanic cements, the addition of fly ash should be taken carefully. Pozzolanic cement has already contained pozzolan materials, meaning that additional fly ash may affect the early strength development. In order to be used in cement product, the fly ash should meet the criteria from EN 197-1. EN 197-1 is the standard specification of fly ash for cement application regulated by European Union. Here is the table showing the EN 450-1 and EN 197-1 standard for fly ash usage in concrete and cement products.

Table 2.6 Fly Ash Potential Usage Criteria EN 450-1 and EN 197-1

Chemical Compound	**Ready Mix Concrete**	**Cement**
	EN 450-1	**EN 197-1**
SiO_2+ Al_2O_3+ Fe_2O_3	$\geq$ 70%	-
SiO_2	$\geq$ 25%	$\geq$ 25%
LOI	$\leq$ 5%	5% - 7%
SO_3	$\leq$ 3%	-
CaO	$\leq$ 10%	$\leq$ 10%
Alkali (Na_2O)	$\leq$ 5%	-

(American Coal Ash Association, 2003)

Several aspects need to be considered regarding to fly ash usage in concrete and cement. There is potential for air entraining ability to decrease due to high carbon fly ash (high C or LOI) that can reduce the durability in long-term. As already mentioned before, fly ash could reduce the heat of hydration, but in colder climate this condition should be considered.

2.3.2 Fly Ash in Stabilized Base Course

The base course is layer of material that is usually used under the road or pavement. Along with combination of aggregate and activator (lime or cement), fly ash can produce a strong and durable pavement base course. By applying fly ash to stabilized base course, it can become the substitute for crushed stone base course and way more cost effective. The application of fly ash for this product is also known as pozzolanic-stabilized mixture (PSM) (American Coal Ash Association, 2003). Class C fly ash can be used as a stand-alone substituent to the current material of base course, while Class F needs several additions. Lime, and cement kiln dust (CKD) should be added to Class F fly ashes, so that this type of ash can be used for base course. PSM bases have several advantages compared to other base materials. It promises a stronger and more durable mixture for the base course. Also, by using PSM, the cost will be lower as it is a residual materials from coal-based power plant.

There are drawback if the criteria of fly ash is not good enough. PSM quality mostly will be affected by the reactivity and fineness of the fly ash (American Coal Ash Association, 2003). Besides, fly ashes which contain more than 5 percent of sulfur, should be carefully evaluated on its expansion potential from material combination. PSM also has seasonal limitation, in order to gain strength it needs warmer weather so that it can form a firm base.

2.3.3 Fly Ash in Soil Improvement

Fly ash is used as an effective agent to stabilize the chemical component in the soil. Mostly the improvement on soil properties includes the density, water content, plasticity, and strength (American Coal Ash Association, 2003). In strengthening the soil, fly ash will act as stabilizer of bases and backfill as well as reduce lateral earth pressures. There are several factors that affect the usage of fly ash to strengthen the soil which are soil properties, delay time, moisture content at time of compaction, and the addition ratio. Delay time is the elapsed time measured between the first time fly ash make contact with water and final compaction of soil, fly ash and water mixture (American Coal Ash Association, 2003). It is a critical factor as tricalcium aluminate in Class C fly ash easily react when make a contact with water. The shorter the delay time, it is likely to obtain higher strength in soil-fly ash mixture. Water content inside the soil affects the strength of soil-fly ash mixtures as it makes it softer. In case of too wet soil, high lime fly ash can be used as drying agent. The fly ash will react to the water inside the soil and consume it's moisturize environment. The strength of soil-fly ash mixture is also determined by the addition ratio of fly ash itself. Typically 8 to 16 percent from dry weight of soil is added with fly ash. The higher the addition of fly ash, the stronger the soil mixture gets. The usage of fly ash to improve soil can minimize the need for expensive natural aggregates in pavement cross-section.

2.3.4 Fly Ash in Asphalt Pavements

If the transportation cost for fly ash from the power plant is relatively low, it can become the cost effective mineral filler in hot mix asphalt (HMA) paving application. Filler is used to increase the stiffness of asphalt mortar matrix, and improve the rutting resistance of pavements (American Coal Ash Association, 2003).

Table 2.7 Physical Requirement of Fly Ash as Mineral Filler

Particle Sizing		Organic Impurities	Plasticity Index
Sieve Size	**Percent Passing**		
600 µm (No.30)	100	Mineral filler must be free from any organic impurities	Mineral filler must have plasticity index not greater than 4
300 µm (No.50)	95 - 100		
75 µm (No.200)	70 - 100		

(American Coal Ash Association, 2003)

The usage of fly ash in asphalt pavement can also reduce the potential of asphalt stripping. The stripping will be prevented by lime constituent which acts as hydrophobic (water resistant) material. In order to be used a mineral filler, fly ash should be in a dry form. From the perspective of mineral content, fly ash with less than 10 percent of LOI content can perform well as mineral filler. Physical requirements for mineral filler in bituminous paving are stated in AASHTO M 17 as follow:

2.4 Physical Distribution and Transportation

In traditional logistics network, products will flow from one stage to another adjoin one until they are received by the end customers (Bozorgirad, et al., 2012). This movement of product can be called as physical distribution, or simply just distribution. Physical distribution is the process of transferring goods from the point of production to the point of consumption (Arnold, et al., 2008). The main objective of distribution will be to achieve the minimum cost to deliver the goods as well as provide satisfying customer service (on-time delivery, safety, packaging, etc.). Here the basic principle for an efficient transportation and distribution will be economy of scale and economy of distance (Bowersox, et al., 2002). Those economics principle will allow reduction of cost per unit of weight as the size and distance of shipment increase. According to Nugroho (2014) there are 2 participants involved in physical distribution of product, the shipper and carrier. Shipper is the one whom the product want to be shipped, while carrier is the one who ship the product (Nugroho, 2014). Another source described that there are 6 parties that involved. Those 6 parties are the shipper, destination party or consignee, carriers and agents, government, internet, and public (Bowersox, et al., 2002). Below is the relationship diagram among those participants.

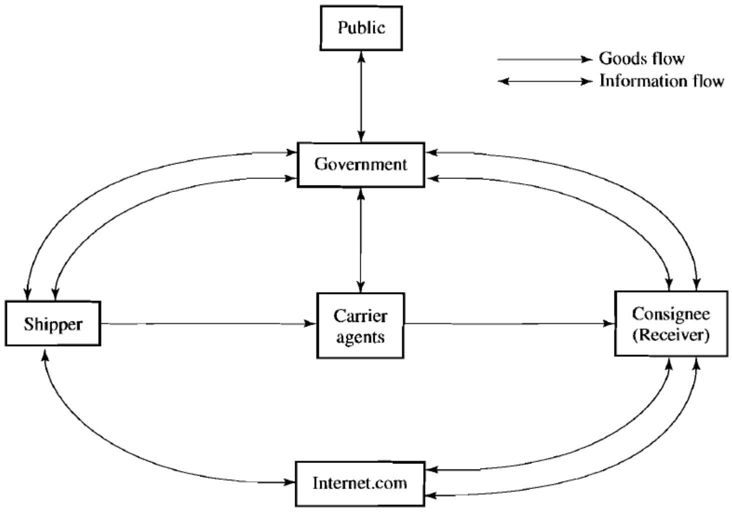

Figure 2.2 Relationship Diagram of Physical Distribution Participants (Bowersox, et al., 2002)

- Shipper and Consignee are grouped together as they both share a similar interest. Both parties require the goods being moved from point of origin to the destination within a given time at lowest cost. In addition, service level provided through specified pickup and delivery, zero loss and damage, and real-time information are also expected.
- Carrier agents is the business that accommodate the need of shipper to transport the goods. The opposite from shipper objective, carrier seeks to charge the customer at highest rate possible while minimizing the operating expenses for moving the goods. To achieve such a goal, most of carriers adopt economic of scale and distance strategy.
- Government plays a big rule in transport or distribution activities. Transportation facilities such as road, pricing, and operating time and area are mostly controlled by government through the regulation, making it the major influence on economic success of the firm. However, those regulation is somewhat needed to create a stable and efficient transportation environment to support economic growth (Bowersox, et al., 2002).
- Internet has provide the platform to ease information sharing. Real-time transaction or tracking through internet is becoming one of key success factor to improve the business visibility as well as the distribution aspect.

The ability to connect business to business as well as business to customer may reduce the time for distribution.

- Public is concerned about the environmental and social impact of the distribution activity. Whether the activity will create pollution or create a harmful potential to the surrounding.

Other than as a way of transporting product, distribution and transportation can be considered as product storage (Bowersox, et al., 2002). During the distribution process inside the vehicle, the goods are being stored. According to Pujawan (2010) in his book titled Supply Chain Management second edition, there are 7 basic functions for distributions and transportation (Pujawan & R., 2010):

1. Segmentation and defining service level. The segmentation is done as there are many types of customers with different characteristics. The contribution of each characteristic into company's revenue is different, therefore segmentation is needed to define the best service level should be provided for each character. In the end, the correct segmentation and targeting service level will result in revenue maximization.
2. Selecting the transportation mode. Transportation mode chosen should be suitable for the type of product and business strategy of the company. Different product may need different type of transportation mode.
3. Information consolidation and shipment. Consolidation is done to achieve the objective of economy of scale and distance. The product from different shippers will be consolidated first before shipping to reduce per unit distribution cost.
4. Scheduling and routing of shipment. Scheduling and routing is an important aspect within distribution activity that accommodates on when and where the product should be shipped. The configuration of schedule and route will give significant impact to the cost associated to distribution and transportation.
5. Provide value added service. Value added activities involved in distribution and transportation include the packaging, labelling, or tag or barcode adding for tracking and tracing.

6. Inventory of product. Slightly different with the explanation by Bawersox (2002), here the intended inventory is warehouse or distribution center (DC). DC exists in between the manufacturer and customer to accommodate things such as consolidation, break bulk, and also as buffer inventory.
7. Accommodate product return. The distribution and transportation activity is not only one way, upstream to downstream, but also downstream to upstream. Product return could happen if customers receive defective product or even product recall from manufacturer itself.

Each company will has its own strategy on how they deliver their product to customer depending on the type of business. Generally there are 4 strategies that can be used in the distribution and transportation strategy.

a. Direct Shipment: the delivery of product is directly made from manufacturer to the customer. This type of strategy can be incorporated for the product that has short life cycle or perishable product or product that is sensitive to the handling. The advantage of using this strategy is of course faster delivery, and no need to invest on buffer facilities. But the disadvantage, the cost per unit of distribution will be high as the economy of scale is not achieved.
b. Intermediate Inventory: there will be buffer facility between manufacturer and customer such as warehouse or DC. This strategy is suitable for product that has long life cycle and the uncertainty is pretty high. The DC will be used to accommodate consolidation and also buffer against uncertainty. The product flow within distribution will be longer than direct shipment.
c. Cross-docking: here the company will has cross-dock facility that is located between the manufacturing facility and customer. In this facility the product from receiving area will be directly combined with other product and go to the shipping dock. By incorporating this strategy, company could achieve economy of scale as well as shorter product flow.
d. Milk-run: within this strategy, the products from manufacturer are not only shipped to one customer, but many customers in one shipping.

In supporting the distribution activity, the selection of transportation mode needs to be suitable with the type of product as well as the business strategy. There are 5 major types of transportation mode that are used by most of companies to distribute the product: truck, rail-way, water transport, plane, and pipeline. Each of those transportation modes has their own characteristics and allotment. Truck mode is relatively cheap, simple, and flexible but the objective of economy of scale is hard to be achieved. Ship or any other water transport maybe the cheapest mode as it can accommodate huge volume so that per unit transport cost is low, but in terms of speed, this mode is too slow. Rail way transportation is offering the ability to carry large volume, and cost effective for long distances, but there is lack in its flexibility. Airplane mode is considered the most expensive among these transportation mode. It can carry quite large volumes, and has the fastest speed to distribute goods. This mode is suitable for high value to weight ratio products, such as electronic devices. The last, pipeline, is dedicated to transport specific product such as oil, gas, and water. Here is the comparison table among those options of transportation mode.

Table 2.8 Transportation Mode Comparison

Operating Characteristics	Rail	Truck	Water	Pipeline	Air
Speed	3	2	4	5	1
Availability	2	1	4	5	3
Dependability	3	2	4	1	5
Capability	2	3	1	5	4
Frequency	4	2	5	1	3

*Lowest rank is better
(Bowersox, et al., 2002)

2.5 Multi-objective Optimization

Unlike ordinary optimization problem, multi-objective or multi-criteria optimization has 2 or more objective functions. In fact, multi-objective problem is more realistic compare to single objective in most real case studies. Among this objective function, it is possible for conflict of interest to occur. For instance to maximize profit, a company should spent more money on marketing. But this option may not be favorable for operational efficiency. This conflict may then produce the trade-offs between different objectives. Multi-criteria optimization is the development from Adam Smith's idea on economic equilibrium in 1776 (Santosa & Willy, 2011). Later on optimality concept was introduced by Pareto that played important role in multi-objective optimization. The Kuhn-Tucker condition then was introduced in 1951 to propose *proper efficiency* concept in this problem.

Multi-objective optimization problem may be in the form of maximization or minimization depends on the problem's owner behalf. Generally multi-objective optimization problem will have the following formulation.

Minimize / Maximize

$$\left(f1(x), f2(x), f3(x), \ldots, fm(x)\right) \tag{2.1}$$

Or: Minimize / Maximize

$$fm(x) \qquad m = 1, 2, \ldots, M \tag{2.2}$$

Subject to

$$hm(x) = 0 \qquad m = 1, 2, \ldots, M \tag{2.3}$$

$$gn(x) \leq 0 \qquad n = 1, 2, \ldots, M \tag{2.4}$$

The constraint may be more than one including inequality, equality and/ or variable bounds to be satisfied. In order to get full understanding of multi-objective optimization problem (MOOP), there are several terms and definitions need to be realized (Amouzgar, 2012).

- **Decision variable and objective space**: the boundary of decision variable is restricted to a lower and upper limit which create the decision variable space. As the objective function is multiple, then multi-dimensional objective space will emerge.

- **Feasible and infeasible solutions**: clearly feasible solution is the one that satisfies all constraints as well as variable bound, while infeasible solution is the opposite of it.
- **Ideal objective vector**: the ideal objective vector is occurred when the value of each objective function is optimum when achieving the total optimum multi-objective value. Generally, ideal objective vector is rarely happened since all objective functions are conflicting to each other.
- **Utopian objective vector**: a vector that all of the components are smaller compared to that ideal objective vector.
- **Linear and non-linear MOOP**: MOOP is categorized as linear if all the objectives and constraints are linear, otherwise if one or more of these parameters are non-linear it is categorized as non-linear MOOP (Deb, 2001).
- **Convex and non-convex MOOP**: the problem is convex if all objective functions and feasible region are convex (Deb, 2001). In non-convex MOOP the solutions are obtained from preference-based approach.
- **Domination (domination, dominating, non-dominated)**: domination is happened when all objectives value in one feasible solution are better compared to another feasible solution. In other word this feasible solution is dominating the second feasible solution. The first feasible solution is called the non-dominated solution.
- **Pareto-optimal set (non-dominated set)**: set of all feasible solutions that are non-dominated by any other solution. The value of objectives function are optimal in which improvement cannot be done without worsening another objective function value.
- **Pareto-front**: Pareto-front is the values of objective functions that related to each solution in Pareto-optimal set in objective space.

2.6 Goal Programming

Goal Programming (GP) is one of multi-objective programming technique (Tamiz & Jones, 1996). The term of GP was first introduced in 1961 by Charnes and Cooper. Here, a soft constraint theory is introduced. Soft constraint is the constraint where it can be tolerated to the most minimum level. The goal of the GP is to minimize such a deviations from the optimum objective. GP models can be classified in two major subsets. The first type is weighted GP. The combination of objective functions, which are the deviations, are weighted according to relative importance of decision maker behalf. The basic formulation weighted goal programming can be constructed as follow.

Minimize

$$a = \sum_{i=2}^{k} (W_{in}\, N_i \; + W_{ip}\, P_i) \tag{2.5}$$

Subject to

$$f_i(x) + N_i - P_i = b_i \quad i = 1 \ldots k \tag{2.6}$$

$$x \in Cs \tag{2.7}$$

The *Ni* and *Pi* represent the negative and positive deviations from the target value *bi*. The weight assigned, W_{in} and W_{ip}, are given respectively to the deviation. The second type of GP is Lexicographic Goal Programming (LGP). Here the deviational variables are assigned in priority order and minimized in lexicographic sense. LGP will solve the problem sequentially. The first priority objective function is solved first. Then the following objective function is solved by maintaining the minimal values reached by higher priority level. The formulation of LGP is given as follow.

Lex min

$$a = (g1(N,P), g2(N,P), \dots, gL(N,P)) \quad \textbf{(2.8)}$$

Subject to

$$f_i(x) + N_i - P_i = b_i \quad i = 1 \dots k \quad \textbf{(2.6)}$$

Under LGP, the model will has L priority levels, and k objectives. The *Ni* and *Pi* represent the negative and positive deviation to the related constraints.

In order to be more efficient to solve either WGP or LGP, several methods can be employed to speed-up the process.

1. **Feasible Basis Creation**: initial basic variable for WGP and LGP in the objective function is given by negative deviational variable if the target value is positive and positive deviational variable if the target value is negative (Tamiz & Jones, 1996).
2. **Variable Fixing**: variable fixing in LGP by solving in priority level, while maintaining the value of higher priority level in minimizing the lower priority levels reduces the size of the model at each priority level.
3. **Restricted Pricing**: eliminate the need to consider deviational variable when finding the simplex entering variable if that variable is already in the basis.
4. **Deviational Variable Exchange**: allowing swapping of deviational variables in the basis at each iteration using amended row-choosing procedure, NPSWAP, by Tamiz and Jones.

Even though it seems that WGP and LGP could give a straight forward solution regarding to multi-objective optimization problem, but there are several shortcomings or considerations need to be noticed described by Tamiz and Jones.

- **Incommensurability**: incommensurability happens when the deviational objective functions with different unit of measure are directly summed. The result may become too extreme, where the goal with greater magnitude too dominate the smaller magnitude goals. There are several methods to do normalization such as Percentage Normalization, Euclidean Normalization, and Summation Normalization as described by Tamiz and Jones. In Percentage Normalization the divisor is the absolute value of right hand side of the objective. For Euclidean Normalization, the divisor is the Euclidean sum of the coefficients of the decision variables in the objective. Euclidean Normalization can be used in many general problem. The last, Summation Normalization, the divisor is the sum of the absolute values of the coefficients of the decision variables in the objectives.

- **Pareto Efficient Solutions**: Pareto efficiency occurs when no objective can be improved without the degradation of another objective (Tamiz & Jones, 1996). Pareto inefficiency in GP can occur when the target values are set too pessimistically. To overcome this problem, there are 2 efficiency restoration that can be employed. The first method is based on the preference on the weights and priority levels. The second method is more on the interactive process to specify which inefficient objectives would like to increase at each iteration.
- **Redundancy in Lexicographic GP**: setting excessive priority number could result in redundancy for lower priority objectives. Re-adjusting priorities, weights, and targets can be done to eliminate the redundant objectives.

CHAPTER 3
RESEARCH METHODOLOGY

In this chapter will be explained the whole process of the research. The research is started from the data collection and literature review and ended when the research objectives are achieved.

3.1 Research Flowchart

The research methodology flowchart is displayed below in Figure 3.1

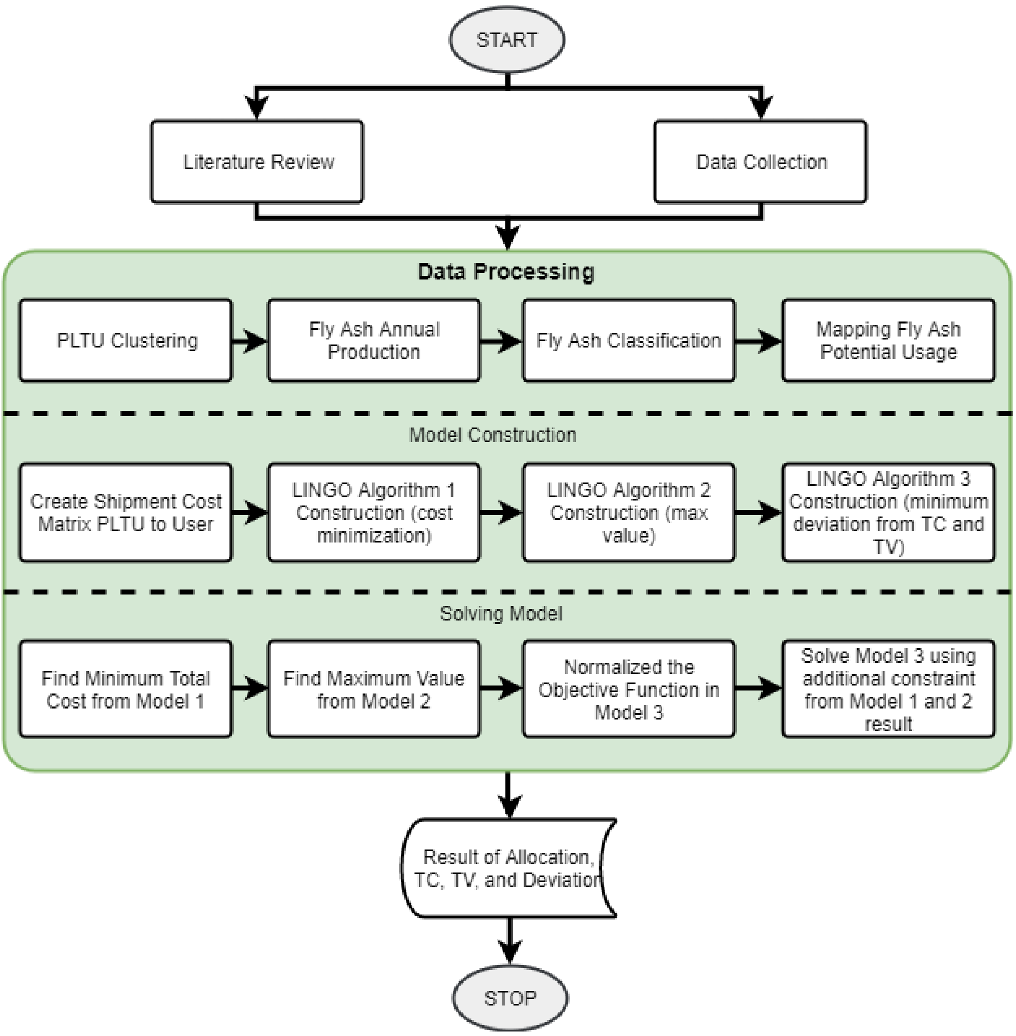

Figure 3.1 Flowchart of Research Methodology

3.2 Research Flowchart Description

Here will be elaborated each stage within the research methodology in detail, that includes the purpose and how it is done.

3.2.1 Literature Review

Literature review is done under the study of transportation, distribution, multi-objective optimization, and fly ash utilization. In this phase the focus will be on the fly ash mapping for different product, and allocation problem with multi-objectives optimization. The source of literature review comes from books, journals, websites, reports, and publications. The purpose of conducting the literature review is to give knowledge and aid in deciding the appropriate method to be used to solve the problem and achieve research objectives.

3.2.2 Data Collection

In this phase, data collection process is done as the input as well as constraint to solve problem occurs in PLN Indonesia. Here secondary data collected by PLN and from trusted online resources is used as the direct observation is not possible and requires many permissions. The data that is required for the input and constraint are as follow:

1. The location of PLTU owned by PLN.
2. The location for potential usage of fly ash that includes cement and concrete industries, and coal mining site to supply coal-based power plant owned by PLN.
3. Production of fly ash from each PLTU.
4. Production capacity of each cement and concrete industries.
5. The chemical compositions of fly ash produced by PLTU
6. Rate of fly ash transportation cost to potential user per truck per km.

3.2.3 Data Processing

Data processing step is done in order to develop the decision support to solve the problem using the data that has been collected before. The data processing stage will be done in several steps that will be explained as follow:

3.2.3.1 PLTU Clustering

In the first data processing step, all of PLTU are clustered based on the region. The clustering is done so that the shipping is more reasonable. By clustering the allocation of fly ash will be shipped to the nearest potential user available in the cluster.

3.2.3.2 Fly Ash Annual Production

Data for fly ash production for the last 3 years from each PLTU is recapitulated and displayed in form of tables. Then the average of fly ash production is calculated to obtain the maximum volume that can be shipped from PLTU. Graphical representation will show the comparison of fly ash production from each cluster.

3.2.3.3 Fly Ash Characterization

The characterization of fly ash is based on the ASTM C618. There are 2 categories of fly ash that are incorporated in this standard, Class F and Class C. The fly ash characterization will be used as the base for mapping its potential usage in cement, concrete, or landfill. The most influential chemical components that determine fly ash class are the silicon, aluminum, and iron.

3.2.3.4 Fly Ash Usage Mapping

In mapping the potential usage of fly ash, EN 450-1 and EN-197-1 standard is employed. The characteristics of each class of fly ash from ASTM C618 characterization also determines the potential usage as EN 450-1 and EN 197-1 are also referring to this standard. Binary variable than will be assigned to the PLTU. Value 1 if the fly ash can be used to produce i product and 0 if it cannot.

3.2.3.5 Shipping Cost from Each PLTU to Potential User

In order to calculate the cost of shipping, the distance matrix is created. The distance matrix will show the distance from PLTU to potential user. The distance that is still within cluster area will use the actual data, while the distance to potential user outside of cluster area will be penalized with big number to indicate that shipping to this location is not preferable.

3.2.3.6 Develop and Solve Allocation Model in LINGO

The development and solving the allocation problem using LINGO are done in the following stages:

1. Determine the input variables that consist of potential user demand, production of fly ash, the shipping cost, and binary variable for fly ash usage.
2. Determine the score for each type of product that include cement, concrete, and landfill.
3. Determine the decision variables which are the quantity of shipping and where the fly ash will be shipped.
4. Create the objective function for calculating minimum total cost, maximum value of absorption, and minimum deviation of cost and value.
5. Create the constraint equation which limit the total of shipping from PLTU i to potential user j up to the production of fly ash PLTU i, and not exceeding the potential of absorption. Below will be shown the mathematical formulation of those 3 model.

Index:

i: PLTU

j: Concrete Plant

k: Cement Plant

l: Landfill

Parameter:

CT_{ij}: Shipping cost per truck from PLTU i to Concrete Plant j

CT_{ik}: Shipping cost per truck from PLTU i to Cement Plant k

CT_{il}: Shipping cost per truck from PLTU i to Landfill l

CS_{ij}: Shipping cost per ton from PLTU i to Concrete Plant j by ship

CS_{ik}: Shipping cost per ton from PLTU i to Cement Plant k by ship

CS_{il}: Shipping cost per ton from PLTU i to Landfill l by ship

V_j: Value generated from each ton of fly ash shipped to Concrete Plant j

V_k: Value generated from each ton of fly ash shipped to Cement Plant k

V_l: Value generated from each ton of fly ash shipped to Landfill l

N_{ij}: Number of truck needed to transport fly ash from PLTU i to Concrete Plant j

N_{ik}: Number of truck needed to transport fly ash from PLTU i to Cement Plant k

N_{il}: Number of truck needed to transport fly ash from PLTU i to Landfill l

P_i: Capacity of fly ash production PLTU i

D_j: Demand of fly ash Concrete Plant j

D_k: Demand of fly ash Cement Plant k

D_l: Demand of fly ash Landfill l

S: Truck capacity

TC: Minimum total cost obtained from model 1

TV: Maximum total value obtained from model 2

Variable:

X_{ij}: Shipping volume (ton) of fly ash from PLTU i to Concrete Plant j

Y_{ik}: Shipping volume (ton) of fly ash from PLTU i to Cement Plant k

Z_{il}: Shipping volume (ton) of fly ash from PLTU i to Landfill l

B_{ij}: Binary variable with the value of 1 if fly ash can be shipped from PLTU i to Concrete Plant j, and value of 0 if it cannot

B_{ik}: Binary variable with the value of 1 if fly ash can be shipped from PLTU i to Cement Plant k, and value of 0 if it cannot

B_{il}: Binary variable with the value of 1 if fly ash can be shipped from PLTU i to Landfill l, and value of 0 if it cannot

D: Deviation of minimum total cost obtained in model 1

V: Deviation of maximum total value obtained in model 2

Model 1:

Objective Function:

Minimize TC =

$$\sum_i \sum_j ((CT_{ij}\, N_{ij} + CS_{ij}\, X_{ij}) B_{ij}) + \sum_i \sum_k ((CT_{ik}\, N_{ik} + CS_{ik}\, Y_{ik}) B_{ik}) + \sum_i \sum_l ((CT_{il}\, N_{il} + CS_{il}\, Z_{il}) B_{il}) \quad \textbf{(3.1)}$$

<u>Subject to:</u>

$$N_{ij} \geq \left(\frac{X_{ij}}{S}\right) \quad \textbf{(3.2)}$$

$$N_{ik} \geq \left(\frac{X_{ik}}{S}\right) \quad \textbf{(3.3)}$$

$$N_{il} \geq \left(\frac{X_{il}}{S}\right) \quad \textbf{(3.4)}$$

$$\sum_j X_{ij}B_{ij} + \sum_k Y_{ik}B_{ik} + \sum_l Z_{il}B_{il} = P_i \quad \textbf{(3.5)}$$

$$\sum_j X_{ij} + \sum_k Y_{ik} + \sum_l Z_{il} = P_i \quad \textbf{(3.6)}$$

$$\sum_i X_{ij} \leq D_j \quad \textbf{(3.7)}$$

$$\sum_i Y_{ik} \leq D_k \quad \textbf{(3.8)}$$

$$\sum_i Z_{il} \leq D_l \quad \textbf{(3.9)}$$

$$B_{ij}, B_{ik}, B_{il} = \{0, 1\} \quad \textbf{(3.10)}$$

$$X_{ij}, Y_{ik}, Z_{il}, N_{ij}, N_{ik}, N_{il} \geq 0 \quad \textbf{(3.11)}$$

$$N_{ij}, N_{ik}, N_{il} \in (integer) \quad \textbf{(3.12)}$$

Model 2:

<u>Objective Function:</u>

Maximize TV =

$$\sum_i \sum_j V_j \, X_{ij} + \sum_i \sum_k V_k \, Y_{ik} + \sum_i \sum_l V_l \, Z_{il} \qquad \textbf{(3.13)}$$

<u>Subject to:</u>

$$\sum_j X_{ij} B_{ij} + \sum_k Y_{ik} B_{ik} + \sum_l Z_{il} B_{il} = P_i \qquad \textbf{(3.5)}$$

$$\sum_j X_{ij} + \sum_k Y_{ik} + \sum_l Z_{il} = P_i \qquad \textbf{(3.6)}$$

$$\sum_i X_{ij} \leq D_j \qquad \textbf{(3.7)}$$

$$\sum_i Y_{ik} \leq D_k \qquad \textbf{(3.8)}$$

$$\sum_i Z_{il} \leq D_l \qquad \textbf{(3.9)}$$

$$B_{ij}, B_{ik}, B_{il} = \{0, 1\} \qquad \textbf{(3.10)}$$

$$X_{ij}, Y_{ik}, Z_{il} \geq 0 \qquad \textbf{(3.11)}$$

Model 3:

<u>Objective Function:</u>

Minimize Deviation =

$$\frac{D}{TC} + \frac{V}{TV} \qquad \textbf{(3.14)}$$

Subject to:

$$N_{ij} \geq \left(\frac{X_{ij}}{S}\right) \tag{3.2}$$

$$N_{ik} \geq \left(\frac{X_{ik}}{S}\right) \tag{3.3}$$

$$N_{il} \geq \left(\frac{X_{il}}{S}\right) \tag{3.4}$$

$$\sum_j X_{ij} B_{ij} + \sum_k Y_{ik} B_{ik} + \sum_l Z_{il} B_{il} = P_i \tag{3.5}$$

$$\sum_j X_{ij} + \sum_k Y_{ik} + \sum_l Z_{il} = P_i \tag{3.6}$$

$$\sum_i X_{ij} \leq D_j \tag{3.7}$$

$$\sum_i Y_{ik} \leq D_k \tag{3.8}$$

$$\sum_i Z_{il} \leq D_l \tag{3.9}$$

$$B_{ij}, B_{ik}, B_{il} = \{0, 1\} \tag{3.10}$$

$$X_{ij}, Y_{ik}, Z_{il}, N_{ij}, N_{ik}, N_{il} \geq 0 \tag{3.11}$$

$$N_{ij}, N_{ik}, N_{il} \in (integer) \tag{3.12}$$

$$\left(\sum_i \sum_j V_j\, X_{ij} + \sum_i \sum_k V_k\, Y_{ik} + \sum_i \sum_l V_l\, Z_{il}\right) + V = TV \tag{3.15}$$

$$\left(\sum_i \sum_j ((CT_{ij}\, N_{ij} + CS_{ij}\, X_{ij})B_{ij}) + \sum_i \sum_k ((CT_{ik}\, N_{ik} + CS_{ik}\, Y_{ik})B_{ik}) + \sum_i \sum_l ((CT_{il}\, N_{il} + CS_{il}\, Z_{il})B_{il})\right) - D = TC \tag{3.16}$$

6. Do verification and validation on the model.
7. Calculate the minimum total cost of shipping objective.
8. Calculate the maximum value of absorption objective.
9. Use the result of minimum total cost and maximum value as a constraint in minimizing the deviation total cost and total value.
10. Do normalization on the objective function in minimizing deviation by giving divisor from the value from step 7 and 8 to the deviation of cost and value respectively.
11. Calculate the minimum deviation from total cost and total value, then add total cost and substract total value with the deviation to obtain final result.

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CHAPTER 4
DATA GATHERING AND PROCESSING

In this chapter will be displayed the result of fly ash allocation to the potential user based on the possibility of usage.

4.1 Scenario and Allocation Result

The basic model is consist of 3 types of objective functions, minimizing total cost, maximizing total value, and minimizing deviation from both minimum total cost and maximum total value. The rule is minimum total cost and maximum total value are calculated first before finding the minimum deviation. In the minimization of total cost, the model will allocate all the fly ash from Power Plant to potential user with the most minimum cost. The cost is consist of 2 types, cost for land transport and sea transport. Fixed cost is charged for each shipping by using truck no matter how much fly ash to be shipped. There will be no difference in shipping cost using truck with the same capacity for fly ash weighted 16 ton or 7 ton. The difference is only on the distance. Meanwhile, in maximizing value, each potential will generate value for each ton of fly ash allocated. The fly ash allocated for cement will generate value of 5 per ton, for geopolymer it is 4 per ton, and 1 per ton for landfill. In the last model, all parameter from both model 1 and 2 is combined, but the objective function is changed to deviation from total cost and deviation from total value.

In this research there are 6 scenarios that will be made. The scenarios are created based on the changing on 2 parameters, capacity of truck and maximum percentage of fly ash usage in cement industry. The scenarios are described as follow:

1. Scenario 1: capacity 20 ton, fly ash for cement maximum 1%
2. Scenario 2: capacity 30 ton, fly ash for cement maximum 1%
3. Scenario 3: capacity 45 ton, fly ash for cement maximum 1%
4. Scenario 4: capacity 20 ton, fly ash for cement maximum 5%
5. Scenario 5: capacity 30 ton, fly ash for cement maximum 5%

6. Scenario 6: capacity 45 ton, fly ash for cement maximum 5%

4.1.1 Cement Allocation

Table 4.1 below shows the result of fly ash allocation for cement usage in each scenario. For example, fly ash from Ombilin, located in cluster Sumatera I, is allocated to Semen Padang only in all scenarios with the amount of 48945 ton. In Air Anyir, from cluster Sumatera II, the fly ash is allocated to Semen Batu Raja in all scenarios, and also to Semen Bosowa Batam in scenario 3. Especially in scenario 1 to 3, there is several differences in either the amount of fly ash allocated and the location of user selected. While in scenario 4 to 6 the allocation result has a little differences. In the scenario 1 to 3 the maximum fly ash to be absorbed is 1%, so that there is limitation to the maximum usage in cement that causes the allocation becomes quite different.

4.1.2 Geopolymer Allocation

The fly ashes used for geopolymer usage are all from cluster in Java. **Table 4.2** below shows the result of fly ash allocation for geopolymer usage in each scenario. For instance, fly ash produced in Rembang is allocated to Waskita Klaten and WIKA Boyolali in all scenarios. The amount of allocation to Waskita Klaten is 30000 ton, while to WIKA Boyolali is vary, in scenario 1 it is 50980 ton while in the other scenarios are 51000 ton. The yellow column indicates that there is no allocation to the user.

4.1.3 Landfill Allocation

The fly ashes used for landfill usage comes from all clusters. **Table 4.3** below shows the result of fly ash allocation for landfill usage in each scenario. For landfill usage, the fly ash is sent back to the sourced of the coal used by the Power Plant. In Sebalang for example, the fly ash is allocated to the Ogan Komering Ulu coal mining site with the quantity of 12150 ton. The allocation of fly ash for landfill is dominated by Power Plant located outside of Java. The main reason is there are still many of them that the fly ash cannot fulfill specification for either cement or geopolymer. There are excessive quantity of fly ash allocated for landfill due to limitation of potential usage in cement industry in scenario 1 to 3.

Table 4.1 Cement Allocation All Scenarios

Cluster	PLTU	Potential User	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
			Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)
Sumatera I	Nagan Raya	Holcim Lhoknga	16262	16262	16262	16262	16262	16262
	Ombilin	Semen Padang	48945	48945	48945	48945	48945	48945
	Teluk Sirih	Semen Padang	12320	12320	12320	12320	12320	12320
Sumatera II	Bukit Asam	Semen Batu Raja	18472	18472	18472	18472	18472	18472
	Air Anyir (Babel)	Semen Batu Raja	2031	2031	2025	2031	2031	2031
		Semen Bosowa Batam			6			
Java II	Tanjung Jati B1&2	Holcim Cilacap	35000			50860	50843	50843
		Semen Gresik Rembang		30000		45425	45442	45442
	Tanjung Jati B 3&4	Semen Gresik Rembang	30000		30000	104558	104558	104558
		Holcim Cilacap		35000	35000			
Java I	Lontar	Indocement Bogor	83930	83930	83925	107743	107743	107730
		Holcim Naragong	23813	23813	23805			
	Pelabuhan Ratu	Indocement Bogor	98070	98070	98055	98070	98070	98070
Java III	Pacitan	Semen Gresik Tuban	34060	34055	68040	68055	68055	68055
		Holcim Tuban	33995	34000				
	Paiton 9	Semen Bosowa Banyuwangi	18000	18000	18000	70202	70202	70202
Total Allocation			**454898**	**454898**	**454855**	**642943**	**642943**	**642930**

Table 4.2 Geopolymer Allocation All Scenarios

Cluster	PLTU	Potential User	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
			Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)
Java II	Tanjung Jati B 1&2	WIKA Boyolali	20					
	Rembang	Waskita Klaten	30000	30000	30000	30000	30000	30000
		WIKA Boyolali	50980	51000	51000	51000	51000	51000
Java I	Suralaya 8	Waskita Bojanegara	24000	24000	24000	24000	24000	24000
		WIKA Krakatau	12300	12300	12285	12300	12300	12283
		WIKA Bogor	19063	19063	19078	19060	19063	19080
	Labuhan	WIKA Bogor	79485	79485	79485	79485	79485	79485
	Lontar	WIKA Krakatau						13
	Indramayu	WIKA Majalengka	60000	60000	59985	60000	60000	60000
		Waskita Subang	17270	17270	17285	17270	17270	17270
	Pelabuhan Ratu	WIKA Krakatau			15			
Java III	Paiton 9	WIKA Pasuruan	52202	52202	52202			
	Tanjung Awar Awar	Waskita Sidoarjo	30597	30597	30597	30597	30597	30597
Total Allocation			**375917**	**375917**	**375932**	**323712**	**323715**	**323728**

Table 4.3 Landfill Allocation All Scenarios

Cluster	PLTU	Potential User	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
			Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)
Sumatera I	Labuhan Angin	Pulau Baai	35554	35554	35554	35554	35554	35554
	Pangkalan Susu	Jambi	3366	3366	3366	3366	3366	3366
Sumatera II	Tarahan	Ogan Komerin Ulu	20188	20188	20188	20188	20188	20188
	Sebalang (Lampung)	Ogan Komerin Ulu	12150	12150	12150	12150	12150	12150
	Suge	Jambi	12430	12430	12430	12430	12430	12430
	Tanjung Balai Karimun	Jambi	554	554	554	554	554	554
Kalimantan	Sanggau (Ketapang)	Kalimantan Tengah	3817	3817	3817	3817	3817	3817
	Pulang Pisau	Kalimantan Tengah	10286	10286	10286	10286	10286	10286
	Asam asam	Asam-Asam	35648	35648	35648	35648	35648	35648
	Balikpapan (Teluk)	Kalimantan Timur	8185	8185	8185	8185	8185	8185
Sulawesi I	Amurang	Kalimantan Timur	25589	25589	25589	25589	25589	25589
	Tidore	Kalimantan Timur	1425	1425	1425	1425	1425	1425
Sulawesi II	Nii Tanasa (Kendari)	Kalimantan Timur	1176	1176	1176	1176	1176	1176
	Barru	Kalimantan Selatan	8552	8552	8552	8552	8552	8552
Nusa Tenggara	Bolok (Kupang)	Kalimantan Selatan	9245	9245	9245	9245	9245	9245
	Ropa (Ende)	Kalimantan Selatan	1441	1441	1441	1441	1441	1441
	Jeranjang (Lombok)	Kalimantan Selatan	6106	6106	6106	6106	6106	6106
Papua	Holtekamp	Kalimantan Selatan	744	744	744	744	744	744

Table 4.3 Landfill Allocation All Scenarios (Con't)

Cluster	PLTU	Potential User	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
			Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)	Quantity (ton)
Java II	Tanjung Jati B 1& 2	Asam-Asam	61265	66285	96285			
	Tanjung Jati B 3&	Asam-Asam	74558	69558	39558			
	Rembang	Kalimantan Selatan	14524	14504	14504	14504	14504	14504
	Adipala	Tarahan	14751	14751	14751	14751	14751	14751
Java I	Lontar	Tarahan			13			
	Suralaya 8	Tarahan				3		
Java III	Pacitan	Asam-Asam			15			
Total Allocation			**361554**	**361554**	**361582**	**225714**	**225711**	**225711**

CHAPTER 5
ANALYSIS AND DISCUSSION

In this chapter will be explained the analysis of allocation result. The analysis and discussion include total cost and total value deviation, fly ash usage comparison, cost comparison, and percentage of cost to value ratio.

5.1 Total Cost and Total Value Deviation Comparison

In this subchapter analysis for each scenario related to the deviation from total cost and total value will be discussed. From the scenario with 1% maximum fly ash for cement, the maximum value obtained is 4,298,858 and the most minimum cost is obtained in scenario 3 where the capacity of the truck is 45 ton. While in the scenario 4 to 6, the maximum value obtained is 4,842,230 with the most minimum cost is also obtained in scenario 6 where the capacity of the truck is 45 ton. As it can be seen from **Table 5.1** to **5.6** below, the total transportation cost is decreasing as the capacity of the truck increases. In terms of the deviation in total cost, in the **Figure 5.1,** it also decreases as the capacity increases. By having larger truck capacity, each Power Plant may has chance to get the advantage from economics of scales because the truck transport cost is fix, whether it is full or not. On the other hand, the deviation on value is not affected by the change in truck capacity. This can be seen from the graph that value deviation from scenario 1 to 3 and scenario 4 to 6 is the same.

Table 5.1 Total Cost and Total Value Scenario 1

Objective Function	Total Value	Total Cost (Rp/year)	
Minimum Total Cost	3,845,061	IDR	142,023,751,362.00
Maximum Total Value	4,298,858	IDR	168,655,289,499.00
Minimum Deviation	4,139,712	IDR	145,188,369,441.00
Deviation	(159,146)	IDR	3,164,618,079.00
	-3.70%	**2.23%**	

Table 5.2 Total Cost and Total Value Scenario 2

Objective Function	Total Value	Total Cost (Rp/year)	
Minimum Total Cost	3,844,950	IDR	123,828,386,040.00
Maximum Total Value	4,298,858	IDR	148,097,936,859.00
Minimum Deviation	4,139,712	IDR	126,374,480,901.00
Deviation	(159,146)	IDR	2,546,094,861.00
	-3.70%	**2.06%**	

Table 5.3 Total Cost and Total Value Scenario 3

Objective Function	Total Value	Total Cost (Rp/year)	
Minimum Total Cost	3,845,053	IDR	100,215,845,788.00
Maximum Total Value	4,298,858	IDR	121,421,220,859.00
Minimum Deviation	4,139,585	IDR	101,925,576,143.67
Deviation	(159,273)	IDR	1,709,730,355.67
	-3.71%	**1.71%**	

Table 5.4 Total Cost and Total Value Scenario 4

Objective Function	Total Value	Total Cost (Rp/year)	
Minimum Total Cost	4,388,408	IDR	125,715,087,924.00
Maximum Total Value	4,842,230	IDR	143,140,705,578.00
Minimum Deviation	4,735,277	IDR	129,657,834,036.00
Deviation	(106,953)	IDR	3,942,746,112.00
	-2.21%	**3.14%**	

Table 5.5 Total Cost and Total Value Scenario 5

Objective Function	Total Value	Total Cost (Rp/year)	
Minimum Total Cost	4,388,415	IDR	107,950,593,177.00
Maximum Total Value	4,842,230	IDR	122,381,400,858.00
Minimum Deviation	4,735,286	IDR	111,141,508,458.00
Deviation	(106,944)	IDR	3,190,915,281.00
	-2.21%	**2.96%**	

Table 5.6 Total Cost and Total Value Scenario 6

Objective Function	Total Value	Total Cost (Rp/year)	
Minimum Total Cost	4,388,405	IDR	84,897,193,611.67
Maximum Total Value	4,842,230	IDR	95,444,273,791.33
Minimum Deviation	4,735,273	IDR	87,114,431,391.33
Deviation	(106,957)	IDR	2,217,237,779.67
	-2.21%	**2.61%**	

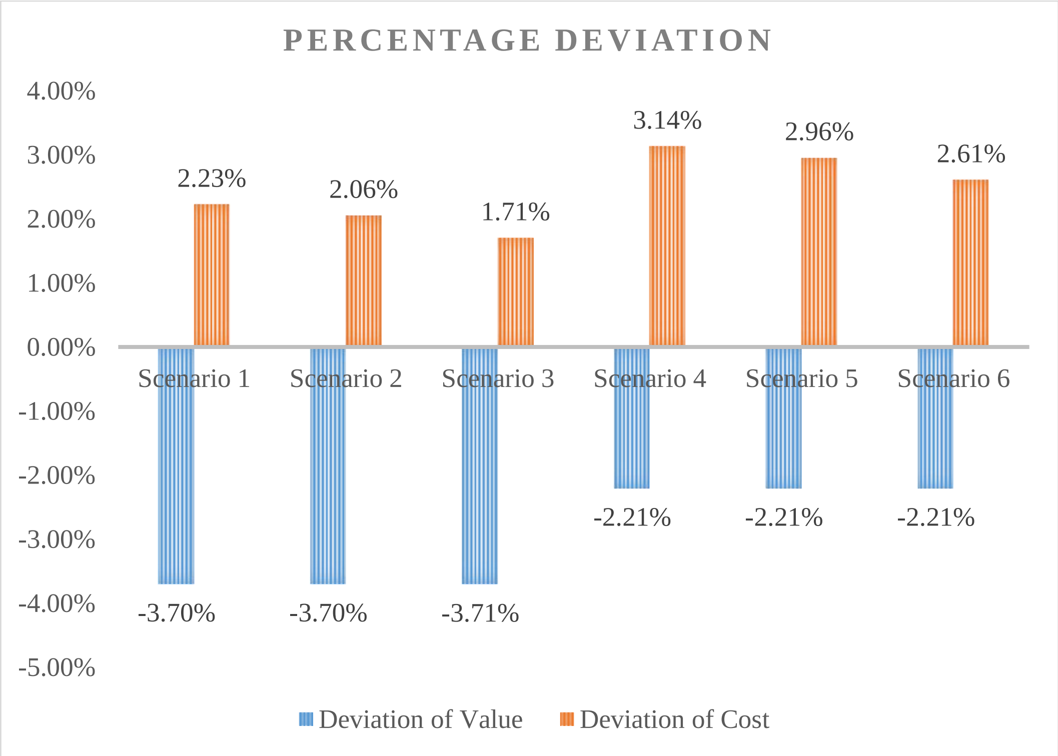

Figure 5.1 Percentage Deviation All Scenarios

5.2 Fly Ash Usage Comparison

In the chapter 4 it is already shown the allocation result from Power Plant to the potential user where the cost is minimized but the value is maximized. Among those scenario, the proportion of fly ash usage for cement, geopolymer, and landfill are shown in the **Figure 5.3** and **5.5** below. Changing from 1% potential to 5% of cement usage has allowed the fly ash to be used more to cement while the landfill usage is significantly decreases. By having potential that has greater value compared to other, in this case cement has a value of 5, geopolymer is 4, and landfill is 1, the fly ash allocation will tend to be allocated to maximize the value while maintaining the cost. If it is compared, fly ash for cement potential has relatively higher proportion, around 38% to 54%, compared to geopolymer which is around 27% to 32% or landfill which is 19% to 30%.

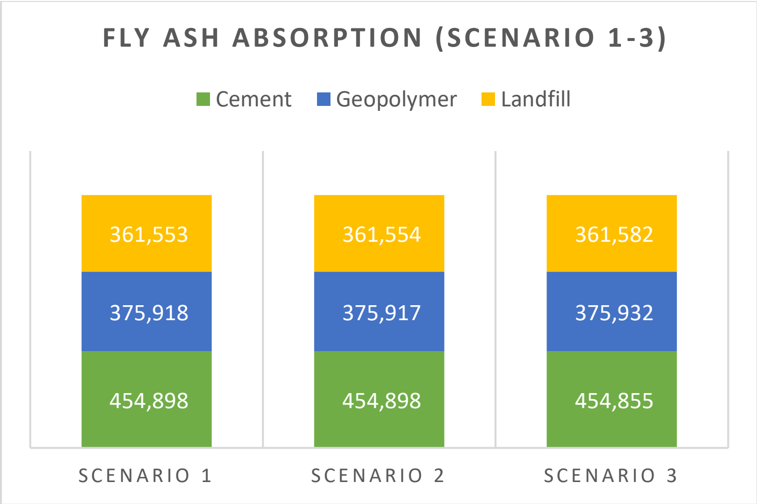

Figure 5.2 Fly Ash Absorption Scenario 1-3

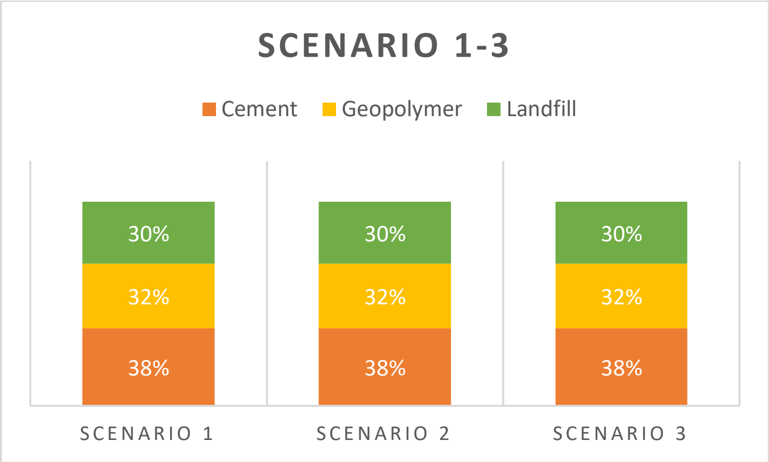

Figure 5.3 Percentage of Fly Ash Usage Scenario 1-3

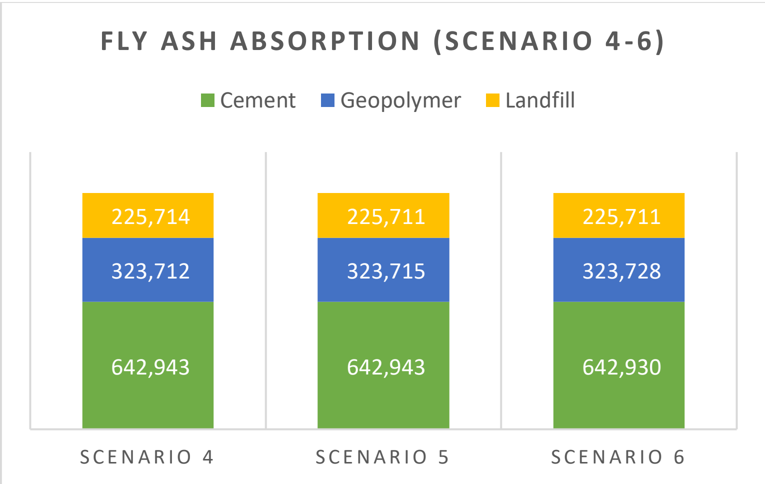

Figure 5.4 Fly Ash Absorption Scenario 4-6

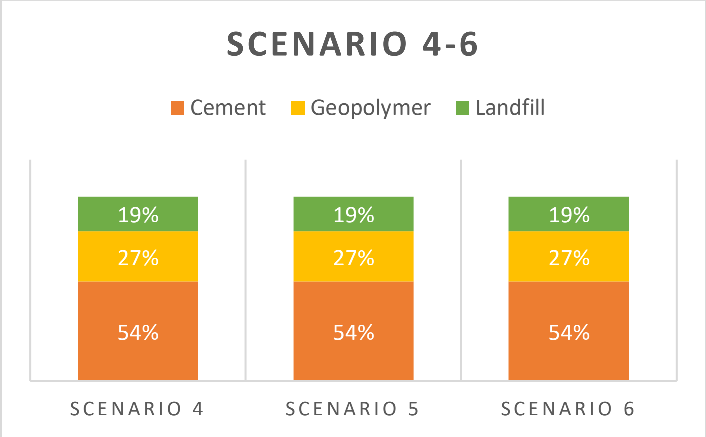

Figure 5.5 Percentage of Fly Ash Usage Scenario 4-6

5.3 Cost Comparison

Here the transportation cost incurred in fly ash allocation is discussed. Compared to the graph in the previous subchapter, the transportation cost proportion is very different. The total transport cost that is incurred to ship fly ash for landfill took more than 50% in average among all scenarios. For example in scenario 3, the cost to transport fly ash for landfill is 66 billion Rupiah while the total cost is around 102 billion Rupiah. By looking at the trend, having larger truck capacity, the percentage of cost to transport fly ash for landfill increases. It means that the shipment for landfill is too small compared to the capacity so that it cannot reach the economics of scales. Moreover, there are so much fly ash that can only be used for landfill because it cannot fulfill the requirement for cement and geopolymer. So that this fly ash should be transported to the dedicated landfill where the coal came from. The problem is most of the landfill location is located far away, across island. That is why the transportation cost becomes uneconomical for delivering fly ash to landfill user.

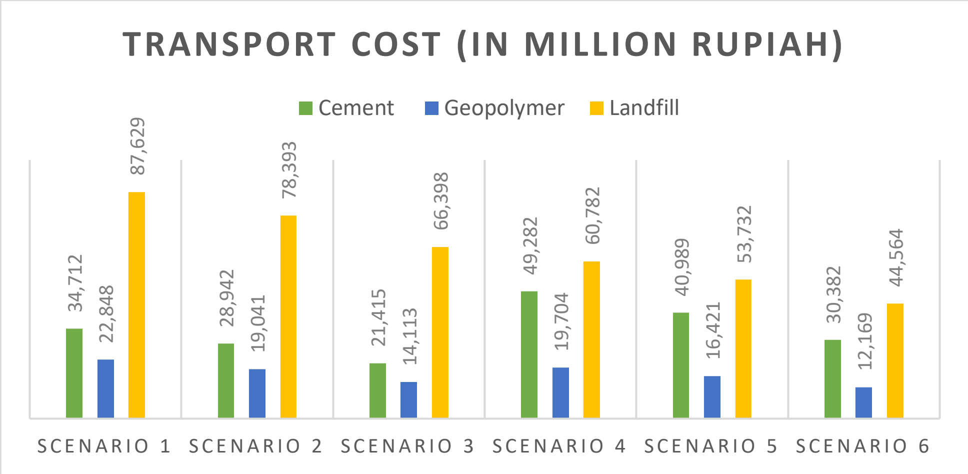

Figure 5.6 Transportation Cost All Scenarios per Usage

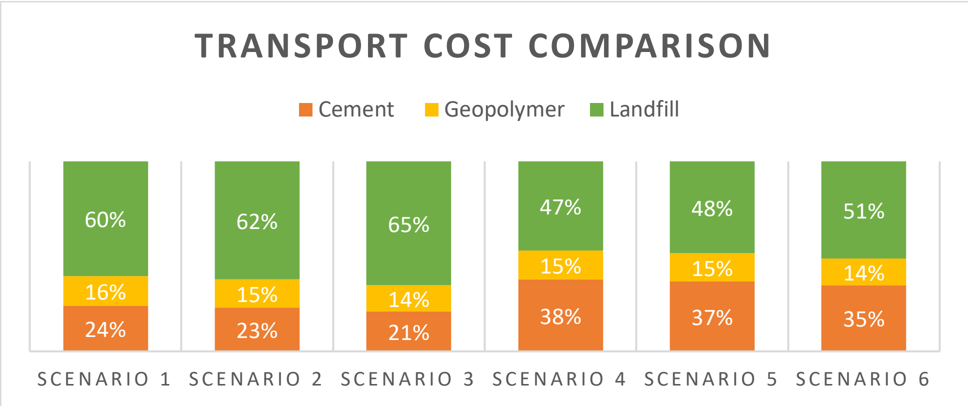

Figure 5.7 Percentage Cost per Usage All Scenarios

5.4 Percentage of Cost to Value Ratio

The ratio of percentage cost to value ratio is used to see how high the impact of value generated to the cost incurred. The lower the ratio the better it is. It should be kept in mind that the value generated is only a rating scale. The cement and geopolymer potential from all scenarios show that each percent of value generated it contributes only 0.38 to 0.56 percent on cost incurred. On the other hand, the ratio of fly ash for landfill is in between 7 to 10. It means that each 1% of the value generated from landfill usage, the cost will 6 to 10 percent from total cost. The value of ratio more than 1 indicates that between the transportation cost and value generated are unbalance. The value that is received from the allocation of fly ash will not be equal to the cost that has to be spent to deliver the ashes.

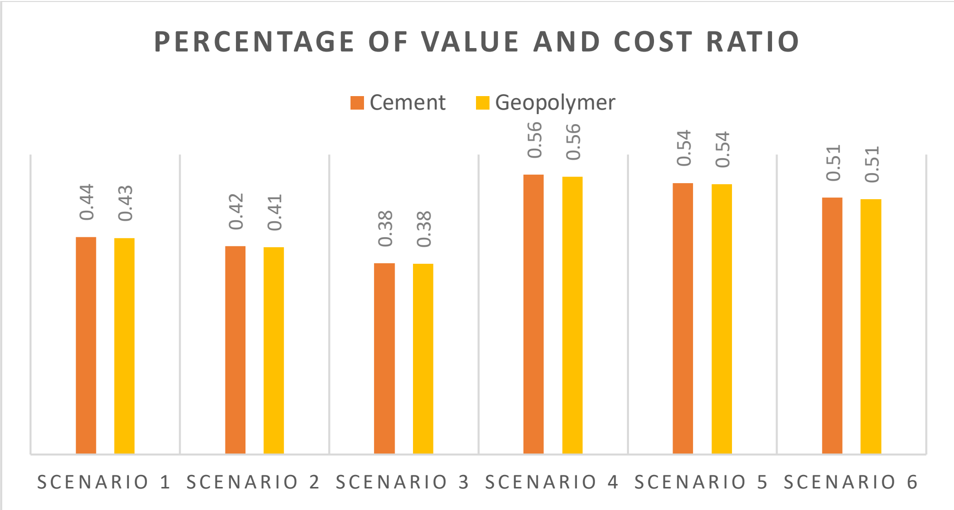

Figure 5.8 Percentage of Cost to Value Ratio (Cement and Geopolymer)

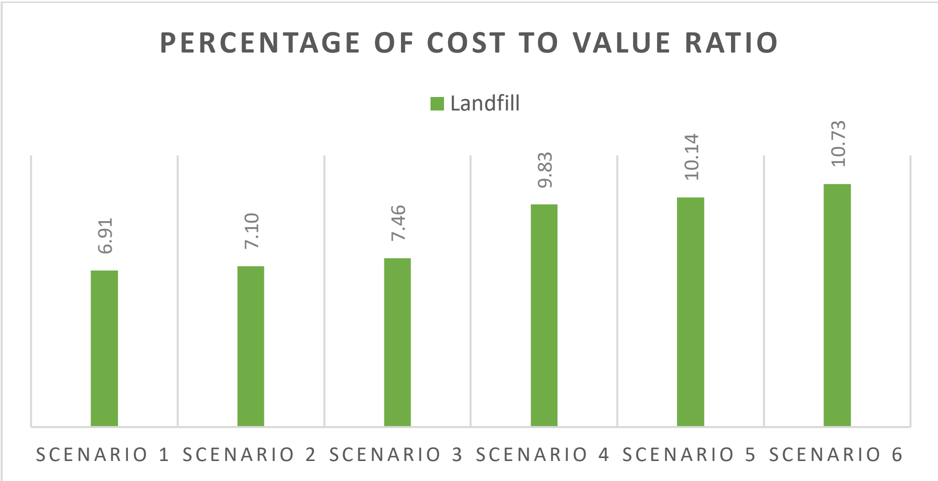

Figure 5.9 Percentage of Cost to Value Ratio (Landfill)

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CHAPTER 6
CONCLUSION AND SUGGESTION

This chapter will discuss the conclusion and suggestion for this research. The conclusions will be drawn from the result of allocation and the analysis related to the cost. The suggestions are addressed both for the PLN regarrding to the decision for fly ash allocation and further improvement of this research.

6.1 Conclusion

1. The fly ash production is mostly dominated by Power Plant located in Java. The production of fly ash in Java contributes to 75% of total fly ash produced from all Power Plant owned by PLN in Indonesia. There are around 38% to 54% of fly ashes allocated for the usage in cement industry, between 27% to 32% of fly ash for geopolymer product, and around 19% to 30% for landfill.
2. From the 6 scenarios, it is obtained that the transportation cost to ship the fly ash to potential user is ranging from 87 billion to 146 billion Rupiah where each scenario has different cost depends on the capacity of truck and the maximum percentage of usage for cement. These costs from each scenario also contribute to different value generated depends on the maximum percentage of usage for cement. In terms of transportation cost, the fly ash shipped for landfill contributes to 50 to 60 percent of total cost on each scenarios while the volume of the shipment is very low. This happens because there are still many Power Plants that the fly ash cannot fulfill the criteria to be used in cement or geopolymer so that it can only be allocated to landfill usage. Moreover most of landfill location is on other island, far away from the Power Plant, this makes the shipment for landfill becomes uneconomical.
3. Based on percentage of cost to value ratio, it is known that for landfill usage, the value generated is not equal to the cost that should be spent to transport

to landfill user. So that it is become consideration to improve the fly ash quality or to spend more money to transport the ash

6.2 Suggestion

1. In order to make better result on estimating fly ash production, other data such as the boiler type and combustion temperature need to be incorporated in the regression equation.
2. There is need to improve the quality of fly ash so that it can fulfill at least the criteria for cement and geopolymer usage.
3. More potential usage other than cement, geopolymer, and landfill could be sought in order to get more options.
4. The volume of fly ash allocation for landfill should be pressed as minimum as possible since the cost is too high.
5. Since the current usage of fly ash in industry is still small, for example in cement it is only 1% compared to 5% from the maximum recommendation, PT PLN needs to approach the potential user to convince to use the fly ash more. This action could be done from the strategic level (decentralized) so that all fly ash in each Power Plant can be distributed equally.

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