A MATHEMATICAL MODEL OF MUNICIPAL SOLID WASTE MANAGEMENT – A CASE STUDY IN KOLKATA

A Dissertation

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By

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DECLARATION

This Dissertation titled "A Mathematical Model of Municipal Solid Waste Management – a Case Study in Kolkata" is prepared and submitted for the partial fulfilment of the requirements for the award of the degree of **Master of Engineering in Civil Engineering** course of Jadavpur University for the session 2018-2019.

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ABSTRACT

The rapidly growing population of the developing countries in the past few decades and accelerated urbanisation has brought the necessity to develop environmentally sustainable and efficient waste management system. The huge generation of MSW and its improper management, especially in developing countries, has become a serious problem for the society. In our present days it has been realized that existing conventional MSW management is unable to manage the generated solid waste properly. Integrated MSW management system is a need of now a days to achieve this goal. So there is a concerned effort to develop a methodology to find optimized path to shift towards integrated MSW management approach. In a developing country like India, a major metropolitan city Kolkata is considered for developing this methodology in this model.

In the study of existing MSW management system of Kolkata, it is found that there is no source segregation, 60% house-to-house collection, 50-55% open vats, 50% operational efficiency of KMC transport system with 30-35% old vehicles, 80% old hired vehicles, informal recycling system, uncontrolled land disposal without having any liner, leachate management and gas collection facility which are causing numbers of environmental and human health hazards to the surroundings. Around 5% recyclables of the garbage is taken out by the informal rag pickers at the households, containers and vat points level. If 5 to 6% of irregular garbage transformation to compost is ignored, rest 95% of the garbage is reaching to the dumping ground, Dhapa. At Dhapa informal rag pickers further segregated out around 4.21% recyclable. So total recovered recyclable is around 9.21% and rest of the garbage is disposed in the landfill along with silt or rubbish.

A mathematical model for a municipal ISWM System is developed in this thesis. Three disposal sites are considered in this model. Each of the three proposed disposal sites at East, North and South has a central sorter, incinerator, composting plant and an engineered landfill site. The constraints include those linking waste flows and mass balance, processing plants capacity, landfill capacity, transport vehicle capacity and number of trips. Recycling has been proposed both at source and at the sorters to segregate out the reusable materials; while composting has been suggested to treat the huge amount of biodegradable materials. On the other hand, compost, which is the end-product of composting, acts as a soil conditioner and can be sold in the market earning revenue. Similarly, incineration has been proposed as a treatment for higher calorific value materials in the waste stream. Power generated from the incinerators adds value to the SWM project. Thus, different treatment options have been included for different fractions of waste stream and treatment will be offered as per the waste stream characteristics.

The linear programming (LP) model integrating the different functional elements was validated and solved by LINGO optimisation software using 2007 KMC datasets. The model shows a very good result. The optimised model provided 7.44% (decrease), 10.77% (decrease) and 0.64% (decrease) deviation from actual KMC expenses in overall SWM cost, transportation cost and landfill cost.

We have run futuristic model with considering three transfer stations and landfill sites. The result shows a minimum of cost when transfer station are near KMC boundary. The result in Run 1, also shows that almost 57.62% waste is going to East landfill site, while 13.99% and 28.3% of waste has entered North and South landfill site respectively.

As because it is a proposed case, so if we construct 3 nos. of transfer station and 3 nos. of landfill then we can manage our generated solid waste in a properly, but in practical situation land acquisition and economy is main reason for our proposed model. So we may not construct all transfer station and landfill site at the same time. We have to construct transfer station along with landfill one by one or any two at a time. For that purpose we do not know which two transfer stations and landfill sites have to construct first for minimizing the cost. Besides in any accidental condition (say technical fault in the bio/thermal processing units, garbage dump landslide, public agitation against accidental spills etc.) one landfill may not be used for depositing purpose. For these cases we have to know the operational change and capacity increment of the other landfill along with their cost implications. If a landfill is most important for minimisation of cost then we should have to fix that problem as soon as possible. We have run the model with 3 nos. of combination. In first combination (Run 2) we have considered East landfill site along with transfer station is not in working condition but other two are in working condition. In second combination (Run 3) we have considered North landfill site along with transfer station is not in working condition but other two are in working condition. In third combination (Run 4) we have considered South landfill site along with transfer station is not in working condition but other two are in working condition.

From the Run 1, result we can say that East landfill should be our first priority. Run 3 shows a minimum cost of SWM among Run 2, Run 3, Run 4. The result of Run 2, Run 3, Run 4 shows that East landfill site is the most important landfill site among the three landfill sites. Then comes South landfill site and at last North landfill site. If any problem occur in East landfill site or in East transfer station then we should have to fix the problem as soon as possible. The results of Run 1, Run 2, and Run 3 shows that South landfill site's capacity should be more than or equal to 56.47%. Similarly from the result of Run 1, Run 2, and Run 4 we can say that North landfill site should be design with a capacity of 43.53% of disposable waste. From result of Run 1, Run 4, and Run 3 East landfill site should be design with a capacity of 92.25% of disposable waste.

But providing a design capacity of 92.25% for East landfill site is not realistic. The use of these amount of design capacity is only when South landfill site is not in working condition. Normally when we consider three landfill site then 57.71 % waste has transferred to East landfill site. Besides if North landfill site is not in working condition then 65.83% waste has transferred to East landfill site. As a solution we have to restrict the maximum capacity of East landfill site along with transfer station and again run the model (Run 5). AS a result from Run 5 total SWM cost (Rs. 16,86,596.00) is increased 0.38% as compare with Run 4 (Rs. 1680212.00). The increased amount of total SWM cost is Rs. 6384.00 per day. It is more realistic than Run 4. So design capacity of East landfill site will be 65.83% of disposable waste.

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List of Abbreviations

ADB	Asian Development Bank
C/N	Carbon / Nitrogen ratio
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health & Environmental Engineering Organisation
DP	Dumper-Placer
EAP	East Asia and the Pacific
ECA	Eastern and Central Asia
EPA	Environmental Protection Agency (USEPA)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GNP	Gross National Product
ICS	Intermediate/Central Sorting facility
ISWM	Integrated Solid Waste Management
KEIP	Kolkata Environmental Improvement Project
kg	Kilogram
km	Kilometer
KMC	Kolkata Municipal Corporation
kWh	kilowatt-hour
LAC	Latin America and the Caribbean
LCV	Lower Calorific Value
LP	Linear Programming
MENA	Middle East and North Africa
MoEF	Ministry of Environment & Forests, Govt. of India
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MT	Metric Tons; 1 MT = 1000 kg

NEERI	National Environmental Engineering Research Institute
O & M	Operation & Maintenance
OECD	Organization for Economic Co-operation and Development
RDF	Refuse Derived Fuel
SAR	South Asia Region
SWM	Solid Waste Management
UNEP	United Nations Environmental Program
USEPA	United States Environmental Protection Agency
VOCs	Volatile organic carbon compounds

1. INTRODUCTION

Waste, a natural part of the life cycle, occurs when any organism returns substances to the environment. Living things take in raw materials and excrete wastes that are recycled by other living organisms. Ever since the ancient times, humans and animals have used the resources of the earth to support life and discarded the useless or unwanted residues called waste **(Tchobanoglous et. al., 1997)**. However, humans produce a huge flow of material residues that would overload the capacity of natural recycling processes, are called wastes, must be managed in order to reduce their effect on our aesthetics, health, or the environment. Solid Waste Management (SWM) is defined as the discipline associated with generation, storage, collection, transport or transfer, processing and disposal of solid waste materials in a way that best addresses the range of public health, conservation, economics, aesthetic, engineering and environmental considerations. The main objective of solid waste management is to reduce and if possible, eliminate adverse effects of waste materials on human health, environment and to manage the increasing solid waste in a suitable way without making any harm of not only our but also the future generation of animal, plant and every living things in the world.

Solid waste is the unwanted or useless solid materials which is generated from different sources like combined residential, industrial, institutional and commercial activities in an area. It may be categorised according to its origin (domestic, industrial, commercial, construction or institutional); according to its constituents (organic material, glass, metal, plastic paper etc.); or according to hazard potential (toxic, non-toxin, flammable, radioactive, infectious etc.). Now a days we have to take the solid waste seriously because of its day to day increase in volume. Rapid population growth, rapid urbanization and uncontrolled industrial development are seriously degrading the urban and semi urban environment in many of the world's developing countries, placing an enormous strain on natural resources and undermining effective and sustainable development. Due to the rapid urbanization of the world, the amount of municipal solid waste (MSW), one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanization. It is estimated that in 2012, globally MSW generation levels are approximately 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years. MSW generation rates are influenced by economic development, the degree of industrialization, public habits, and local climate. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. Urban residents produce about twice as much waste as their rural counterparts.

The urban growth in India is faster than the average for the country and far higher for urban areas over rural. Due to continuous migration of population from rural areas to towns and cities, in India the share of urban population has increased from 27.84% in 2001 to 31.8% in 2011 and likely to reach 50% by 2030. Presently out of a population of 1.21 billion approximately 377 million urban people are residing in 7,935 towns and cities with 4041 municipal authorities **(CPHEEO, 2016)**. There are three megacities - Greater Mumbai, Kolkata and Delhi, which have a population exceeding 10 million, 53 cities which have more than 1 million population and 415 cities whose population exceeds 0.1 million **(Joshi and Ahmed, 2016)**. Accelerating urban population coupled with increasing per capita income and subsequent increase in MSW generation has made many Indian cities deficient in basic infrastructure of SWM services. The urban population in India generated about 1,14,576 MT/day of MSW in 1996; 1,27,486 MT/day during 2011-12; and 1,50,000 MT /day during 2014-15 and likely to reach 260 million tons per year by 2047 **(CPHEEO, 2016)**.

Management of municipal solid waste resulting from rapid urbanization has become a serious concern for Municipal Corporations, Government Departments, Urban Development Authorities, regulatory bodies and also for the public in most of the developing countries.

In many of the developing countries like India uncontrolled land disposal of municipal solid waste i.e. crude open dumping is still the main disposal method even today **(CPHEEO, 2016)**. The wastes are thrown over the streets and drains and the cities resort to indiscriminate dumping of domestic, commercial, industrial and bio-medical waste; electrical and electronic equipment without any treatment. This leads to contamination of surface and ground by the leachate. Physical, chemical and biological processes occurring simultaneously at the dump sites result in waste decomposition as well as generation of highly polluted leachate and hazardous landfill gases. Chemically contaminated leachates are one of the by-products in landfill degradation reactions **(O'Learly and Walsh, 1995)**. One of the severe problems associated with the open dumps is infiltration of leachate into the surrounding environment, subsequent contamination of the land and water **(Kumar et al., 2002)**. It is essential to protect ground and surface waters and soil from contamination due to leachate percolation in and around dump sites. Besides that in sea costal area we are throwing our waste to the surface water like sea, river, which make a serious harm to plant, fish, insect etc. in water body. Due to anaerobic conditions within a biologically active open dumping and landfilling, both of which are known to result in significant greenhouse gases emission, particularly methane that has significantly higher effect on global warming. It also produce carbon-di-oxide, water and various trace components such as ammonia, sulphide and non-methane volatile organic carbon compounds (VOCs). The 100 year global warming potential of CH_4 is 25 times greater than that of CO_2 **(Hettiaratchi, 2003)**.

The main problem of the developing countries like India is deficiency of manage the huge amount of waste. The problem of waste management are many for developing countries. Most important cause is the economy of developing countries are poor. Though people from poorer countries tend to buy fewer products with less packaging, and they produce less waste than developed countries or other industrialized nation but on the other hand, unlike developed nations, poorer countries in the developing world often have not developed adequate waste management policies or systems, trash collection services, or government institutions to properly manage their waste. Laws related to solid waste often lax-burning of garbage and open dumping allowed. Mainly a lack of funds prevents municipalities in developing countries from creating a solid waste management system. Also the lack of status and poor salaries associated with the profession, discourages qualified employees to work for collection, manage, dumping of solid waste.

There is an urgent need to research towards a solid waste management system which is environmentally, economically and socially sustainable. Proper municipal solid waste management demands the application of the principles of Integrated Solid Waste Management (ISWM) **(CPHEEO, 2016)**. To minimize the huge impact of a large amount of generating solid waste in our day to day life, Integrated Solid Waste Management (ISWM) is required. ISWM represents a contemporary and systematic approach to solid waste management. The U.S. Environmental Protection Agency (EPA) defines ISWM as a complete waste reduction, collection, composting, recycling and disposal system. An efficient ISWM system considers how to reduce, reuse, recycle, and manage waste to protect human health and natural environment. The ISWM approach is designed to minimise waste generation at source, then further reduce the waste by reusing, recycling and processing (with or without material and energy recovery) and subsequently dispose the treated waste in an engineered/sanitary landfill.

Managing the waste is a complex task which requires proper technical solution, sufficient organizational capacity, and co-operation between a wide range of stakeholders. For this system approach and model study is important in ISWM. According to **Seadon (2010)**, the interdisciplinary and multi-sectoral consideration needed for the proper management of solid waste – manufacturing, transportation, urban growth and development, land use patterns, public health, etc. highlights "the interaction and complexity between the physical components that include the social and environmental spheres. So there is a need to formulate a mathematical model for the Integrated Solid Waste management of a city of a developing country. For this purpose Kolkata, India may be selected to develop the methodology for the developing countries to arrive at the optimum sustainable operating plan for the integrated MSW management system under given set of socio-economic and environmental conditions.

2. LITERATURE REVIEW

2.1 MUNICIPAL SOLID WASTE GENERATION — INDIA AND ABROAD

According to US EPA "solid waste" means any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, resulting from industrial, commercial, mining, and agricultural operations, and from community activities. It is important to note that the definition of solid waste is not limited to wastes that are physically solid. Many solid wastes are liquid, semi-solid, or contained gaseous material. As per Ministry of Environment & Forests, India (MoEF), 2000 literature, 'Municipal Solid Waste' includes "commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes." Thus, MSW may comprise of components as elaborated in Table 2.1

Table 2.1 Sources and types of MSW **(UNEP, 2002)**

Sources	Typical Waste Generators	Components of MSW
Residential	Single and multifamily dwellings	Food waste, paper, cardboard, plastics, textiles, glass, metal, ashes, special wastes (bulky items, consumer electronics, batteries, oil, tyres) and household hazardous wastes
Commercial	Stores, hotels, restaurants, markets, offices	Paper, cardboard, plastic, wood, food waste, glass, metals, special wastes, hazardous wastes
Institutional	Schools, government buildings, hospitals, prisons	Paper, cardboard, plastic, wood, food waste, glass, metals, special wastes, hazardous wastes
Municipal services	Street cleaning, landscaping, parks, beaches, recreational areas	Street sweepings, inert, automobile parts, construction and demolition wastes, dead animal carcass, tree trimmings and yard waste, general wastes from parks

Solid waste management is a function of combination of various activities such as generation, collection, transportation, processing and disposal. The main purpose of SWM is to create an uncontaminated, safe and healthy environment without disturbing natural resources for our future generation. A proper SWM helps safe disposal, waste reduction and minimisation, and promotes refuse/ re-use /recycling. On the other hand, an improper SWM system deteriorates public health, causes environmental pollution, degrades natural resources, enhances climate change and adversely affects the quality of life of citizens and animal.

MSW has become a global challenge due to limited resources, increasing population, rapid urbanization and industrialization. Day by day rapid increase in volume and types of solid and hazardous waste as a result of economic growth, urbanization and industrialization, is going to be a serious problem for national and local governments to ensure effective and sustainable management of waste. Current global MSW generation levels are approximately 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years **(World Bank 2012)**. The huge amounts of municipal solid waste (MSW) create enormous challenges for all developed or developing countries across the whole economic spectrum. The Table 2.2 shows the per capita MSW generation in different countries **(Hoornweg and Bhada-Tata, 2012)**.

Table 2.2 Per capita MSW generations in different countries

Country	**Quantity (kg/capita/day)**
India	0.34-0.37
U.S.A.	1.25-2.58
U.K.	1.34-1.79
Singapore	0.94-1.49
Japan	0.9-1.71
China	0.31-1.02
Indonesia	0.49-0.52

MSW generation rates are influenced by economic development, the degree of industrialization, public habits, and local climate. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. Income level and urbanization are highly correlated and as disposable incomes and living standards increase, consumption of goods and services correspondingly increases, as does the amount of waste generated. Urban residents produce about twice as much waste as their rural. However, global waste generation is varying with region, country, city, and even within cities.

The annual waste generation in East Asia and the Pacific (EAP) Region is approximately 270 million tons per year. This quantity is mainly influenced by waste generation in China, which makes up 70% of the regional total. Per capita waste generation ranges from 0.44 to 4.3 kg per person per day for the region, with an average of 0.95 kg/capita/day **(Hoornweg et al 2005)**.

According to the World Bank 2012 report--

Waste generation in sub-Saharan Africa is approximately 62 million tonnes per year. Per capita waste generation is generally low in this region, but spans a wide range, from 0.09 to 3.0 kg per person per day, with an average of 0.65 kg/capita/day.

In Eastern and Central Asia (ECA), the waste generated per year is at least 93 million tonnes. The per capita waste generation ranges from 0.29 to 2.1 kg per person per day, with an average of 1.1 kg/capita/day.

Latin America and the Caribbean (LAC) has the most comprehensive and consistent data (e.g. PAHO's Regional Evaluation of Solid Waste Management, 2005). The total amount of waste generated per year in this region is 160 million tonnes, with per capita values ranging from 0.1 to 14 kg/capita/ day, and an average of 1.1 kg/capita/day.

In the Middle East and North Africa (MENA), solid waste generation is 63 million tonnes per year. Per capita waste generation is 0.16 to 5.7 kg per person per day, and has an average of 1.1 kg/capita/day.

In South Asia Region (SAR), approximately 70 million tonnes of waste is generated per year, with per capita values ranging from 0.12 to 5.1 kg per person per day and an average of 0.45 kg/capita/day.

The OECD (Organization for Economic Co-operation and Development) countries generate 572 million tons of solid waste per year. The per capita values range from 1.1 to 3.7 kg per person per day with an average of 2.2 kg/capita/day.

Figure 2.1 illustrates global waste generation per region, where OECD countries make up almost half of the world's waste, while Africa and South Asia seen as the regions that produce the least waste.

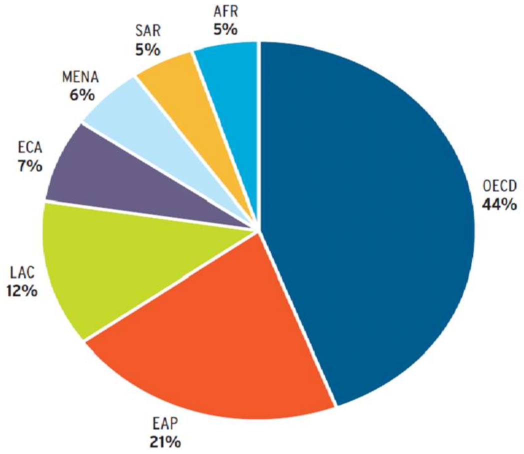

Figure 2.1 Waste generation by region **(World Bank 2012)**

High-income countries produce the most waste per capita, while low income countries produce the least solid waste per capita. Table 2.3 shows MSW quantities and per capita generation in Indian cities **(CPCB, 2012)**.

Table 2.3 Quantities of MSW and per capita generation in Indian cities **(CPCB, 2012)**

City	MSW generated (MT/day)		
	1999-2000[a]	2004-2005[b]	2010-2011[c]
Ahmedabad	1683	1302	2300
Bangalore	2000	1669	3700
Bhopal	546	574	350
Mumbai	5355	5320	6500
Kolkata	3692	2653	3670
Delhi	5700	5922	6800
Hyderabad	1566	2187	4200
Jaipur	580	904	310
Kanpur	1200	1100	1600
Lucknow	1010	475	1200
Chennai	3124	3036	4500
Surat	900	1000	1200

a EPTRI survey ; b NEERI-Nagpur survey; c CIPET survey

Researchers **(Srivastava et al., 2015)** suggest per capita rate of MSW generation in India ranges from 0.2 to 0.6 kg/day; the amount of MSW generated per capita is estimated to increase at a rate of 1– 1.33% annually. As per **CPHEEO 2016**, during 2013-2014, the average rate of waste generation in India was 0.11 kg/day out of which 82% was collected and only 22.9% was treated. The waste generation rate is between 200-300 gm/capita/day in small towns and cities (population less than 2 lakhs); for cities with a population between 2 to 5 lakhs, the waste generation rate is around 300-350 gm/capita/day; 350-400 gm/capita/day in cities with population 5 lakhs to 1 million; and 400-600 gm/capita/day in cities with population exceeding 1 million. With increasing urbanization and changing lifestyles, Indian cities now generate eight times more MSW than they did in 1947 **(Kaushal et al., 2012)**. Between 2001 to 2011, there has been an almost 50% increase in total MSW generation. India is thus facing a sharp contrast between its increasing urban population and available services and resources.

2.1.1 Past Studies on Solid Waste Generation of Kolkata

Study of various reports prepared in the past for Kolkata shows a wide range of variation in generation. Further the modality of quantity estimation has not been spelt out in any of these reports. Total quantity of MSW generation assessed in these reports **(ADB, 2005)** as explained in Table 2.4.

Table 2.4 Study reports on assessed quantity of MSW generation of Kolkata **(ADB, 2005)**

Sl. Nos.	Source	Year of estimation	Estimated quantity (MT/d)
1.	Talukdar Committee's Report	1963	2115
2.	Mr. M.G. Kutty's Report	1963	1500
3.	NEERI Report	1970	1640
4.	Task Force(CMDA Report)	1973	1600-1800
5.	Report of CE (MV & CON), CMC	1983	1800
6.	Calcutta Management Association Report (10 Boroughs)	1985-87	1750+200(silt)
7.	Report of Institute of Local Govt. & Urban Studies	1992	3150
8.	Report of CMC	1993	3100-3400
9.	Report of KMC on assessment	1999	2400+200(silt)

2.2 COMPOSITION OF SOLID WASTE

The analysis of refuse is carried out normally to know its physical as well as chemical characteristics which help in designing and selecting the collection, processing and disposal aspects of the system **(Flintoff, 1984)**. Collection of samples is the first step in estimating the composition of MSW and should be carefully decided to ensure truly representative samples. In general, one sample should be collected randomly from each identified truck. If more than one sample is needed, should be collected from different parts of the load in the truck.

In Kolkata as well as in India stratified random sampling method is very difficult because of the complexity in accurately dividing the population into various socio economic groups. Therefore quartering method may be suitable in India as well as in Kolkata **(NEERI, 1995)**.

In the municipal solid waste stream, waste is broadly classified into organic and inorganic. In this study, waste composition is categorized as organic, paper, plastic, glass, metals, and 'other.' An important component that needs to be considered is 'construction and demolition waste' (C&D), such as building rubble, concrete and masonry. In some cities this can represent as much as 40% of the total waste stream. Waste composition is influenced by many factors, such as level of economic development, cultural norms, geographical location, energy sources, and climate. Even in the same country, it may change from one city to another. As a country urbanizes and populations become wealthier, consumption of inorganic materials (such as plastics, paper, and aluminium) increases, while the relative organic fraction decreases. Generally, low and middle-income countries have a high percentage of organic matter in the urban waste stream, ranging from 40 to 85% of the total. Paper, plastic, glass, and metal fractions increase in the waste stream of middle- and high-income countries. MSW is heterogeneous in nature and consists of a number of different materials derived from various types of activities. The consumption of raw materials and finished product by a community is directly proportional to the Gross National Product (GNP) of the country. Since the solid waste quantities are directly proportional to the quantity of material consumed, the increase in per capita solid waste quantity would be directly proportional to the per capita increase in GNP. The average per capita waste generation in India is around 0.4 kg as compared to 1.26 kg for Denmark, 2 kg in U.S., 1.89 kg in Australia, 1.29 kg in France and 0.7 kg in China **(Asnani, 2006)**. Variation in composition of solid waste for different degrees of national wealth (per capita income) is given in Table 2.5.

Table 2.5 Composition and characterization of MSW for different income group countries [Central Public Health & Environmental Engineering Organization (CPHEEO),2000]

Composition (% by weight)	**Low Income Countries**	**Middle Income Countries**	**High Income Countries**
Metal	0.2-2.5	1-5	3-13
Glass, Ceramics	0.5-3.5	1-10	4-10
Food & garden waste	40-65	20-60	20-50
Paper	1-10	15-40	15-40
Textiles	1-5	2-10	2-10
Plastics/ Rubber	1-5	2-6	2-10
Misc. Combustible	1-8	-	-
Inert	20-50	1-30	1-20
Density (kg/m^3)	250-500	170-330	100-170
Moisture Content (% bywt)	40-80	40-60	20-30
Waste Generation (kg/cap/day)	0.4-0.6	0.5-0.9	0.7-1.8

A comparison of the current waste composition in Asian countries (Table 2.6) **(IGES, 2001)** shows that comparatively developed countries like Japan, China, Korea generates lower percentage of organic waste (17 to 36%) than Sri Lanka, Indonesia, Myanmar (70 to 80%). The composition differs depending on the economic level of cities as well as other factors such as geographic location, energy sources, climate, living standards and cultural habits and the sources of wastes.

Table 2.6 Percentage composition of urban solid waste in selected Asian countries **(IGES, 2001)**

Country	Organic Waste	Paper	Plastic	Glass	Metal	Others
China	35.8	3.7	3.8	2.0	0.3	54.3
Hong Kong	37.2	21.6	15.7	3.9	3.9	17.6
Indonesia	70.2	10.9	8.7	1.7	1.8	6.2
Japan	17.0	40.0	20.0	10.0	6.0	7.0
Laos	54.3	3.3	7.8	8.5	3.8	22.5
Malaysia	43.2	23.7	11.2	3.2	4.2	14.5
Myanmar	80.0	4.0	2.0	0.0	0.0	14.0
Philippines	41.6	19.5	13.8	2.5	4.8	17.9
Singapore	44.4	28.3	11.8	4.1	4.8	6.6
South Korea	31.0	27.0	6.0	5.0	7.0	23.0
Thailand	48.6	14.6	13.9	5.1	3.6	14.2
Abu Dhabi	22.5	42.4	6.3	4.4	14.0	10.4
Lahore, Pakistan	49	4	9	3	4	31
Sri Lanka	80	8	2	6	1	3

The ratio of paper and plastics including voluminous materials such as food containers and wrapping materials is higher in developed cities. On the other hand wastes in developing cities have a high organic content and a low calorific value. Biological treatments such as composting and bio-gasification are thus most suitable. Physical and chemical characteristics of municipal solid waste in some of the cities in India are shown in Table 2.7.

Table 2.7 Physical and chemical characteristics of municipal solid waste of a few India cities **(Srivastava et al., 2015)**

Description	**Delhi**	**Mumbai**	**Chennai**	**Kolkata**	**Hyderabad**
Population (million)	10	13.8	5.8	7.0	4.2
MSW (tons/day)	+5000	+6400	+4000	+3000	+2200
Recyclables (%)	15.52	16.66	16.34	11.48	21.6
Others (including inert) [%]	30.06	20.9	42.32	37.96	24.20
Biodegradable/ Organic (%)	54.42	62.44	41.34	50.56	54.20
Moisture content (%)	49	54	47	46	46
C/N ratio	34.87	39.04	29.25	31.81	25.90
HCV (kcal/kg)	1802	1786	2594	1201	1969

2.3 IMPACT OF SOLID WASTE

Improper MSW disposal and management causes all types of pollution: air, soil, and water. Indiscriminate dumping of wastes contaminates surface and ground water supplies. In urban areas, MSW clogs drains, creating stagnant water for insect breeding and floods during rainy seasons. Uncontrolled burning of MSW and improper incineration contributes significantly to urban air pollution. Greenhouse gases are generated from the decomposition of organic wastes in landfills, and untreated leachate pollutes surrounding soil and water bodies. Health and safety issues also arise from improper MSWM. Insect and rodent vectors are attracted to the waste and can spread diseases such as cholera and dengue fever. Using water polluted by MSW for bathing, food irrigation and drinking water can also expose individuals to disease organisms and other contaminants. The U.S. Public Health Service identified 22 human diseases that are linked to improper MSWM. Waste worker and pickers in developing countries are seldom protected from direct contact and injury, and the co-disposal of hazardous and medical wastes with MSW poses serious health threat. Exhaust fumes from waste collection vehicles, dust stemming from disposal practices and the open burning of waste also contribute to overall health problems. People know that poor sanitation affects their health, especially in developing and low-income countries, where the people are the most willing to pay for environmental improvements **(Rathi, 2006).**

2.3.1 Health effect of Bio gas

A number of polluting gases can have a variety of impacts on health. CO_2 and CH_4 are greenhouse gases partially responsible for global warming.

Methane

The accumulation of CH_4 in confined spaces or enclosed structures can result in asphyxia, explosions, and fires, which may cause injury or loss of life. The risk of CH_4 gas explosions is highest at ambient concentrations of between 5% and 15%. Underground migration of biogas (lateral migration) can result in its infiltration into buildings and can cause explosions or asphyxia in confined spaces **(Williams, 2002)**.

CO_2

The greenhouse effect is a natural phenomenon that traps radiation within earth's atmosphere. A higher concentration of greenhouse gases means a warmer climate. CO_2 is considered the predominant greenhouse gas and has the greatest impact on global heat.

Organic Compounds at Low Concentrations

A number of organic compounds are toxic, including several VOCs, which can cause health problems following chronic exposure. These include, for example, aplastic anemia; teratogenic and fetotoxic effects; damage to the liver, lungs, and kidneys; nervous system damage; and various cancers, such as leukaemia and myelomas **(Škulte΄tyova, 2011)**. It is important to note, however, that these effects are associated with high concentrations, which are not necessarily found in proximity to landfills. Those at greatest risk are landfill workers, particularly operators of heavy equipment used to compact the waste.

2.3.2 Landfill leachate

Although waste management hierarchy considers landfilling as a last option, the worldwide trend is still in favour of controlled sanitary landfilling, as the preferred means of disposing both municipal and some solid industrial waste. In spite of many advantages, as the cheapest option in terms of capital and exploitation costs, the major drawback of landfilling resides in the generation of heavily polluted leachates, whose quantity, volumetric flow rate, and chemical composition are highly variable. In addition, landfill outputs induce impacts and risks in the environment, forcing authorities to impose more and more stringent constraints**.** The generation of leachate is caused principally by precipitation percolating through waste deposited in a landfill and has extracted dissolved and suspended materials. Additional leachate volume is produced during the decomposition of carbonaceous material producing a wide range of other materials including methane, carbon dioxide and a complex mixture of organic acids, aldehydes, alcohols and simple sugars. The leachate from landfills contains toxic chemicals including volatile organic compounds (VOCs), nitrogen compounds, inorganic macro components (common cations and anions including sulfate, chloride, iron, aluminium, zinc and ammonia), heavy metals (Cr, Cd, Pb, Ni, Cu, Hg) , and xenobiotic organic compounds such as halogenated organics, (PCBs, dioxins, etc) **(Mor et al., 2006)**.

Environmental Impact of Leachate

The presence of moisture and rainwater leach the pollutant chemicals produced during degradation to dissolve and flow into the groundwater and surface water reserve thereby affecting the flora and fauna of the water body. The dump sites virtually become a breeding ground for all kinds of diseases. Besides this, it leads to formation of secondary pollutants like H_2S, and other hydro sulfurous gaseous pollutants reacting with bacteria present in the waste in the presence of moisture and temperature. CH_4 which is one of such toxic gases produced leads to fire hazards **(Sahu, 2007)**. Pathogenic microorganisms that might be present in it are often cited as the most important, but pathogenic organism counts reduce rapidly with time in the landfill, so this only applies to the freshest leachate.

There has been a serious concern about the possible contamination of soils, ground and surface waters when the wastes are, thus, disposed. A study conducted in the city of Hyderabad clearly showed how soil, surface water as well as ground water have been polluted due to open landfills **(Rao and Shantaram, 2003)**. Consumption of leachate-contaminated ground water may lead to, among other things, heavy metal toxicity such as impaired renal function and possibly cancer.

Leachate streams running directly into the aquatic environment can severely diminish bio-diversity and greatly reduce populations of sensitive species. Where toxic metals and organics are present this can lead to chronic toxin accumulation in both local and far distant populations. Rivers impacted by leachate are often yellow in appearance and often support severe overgrowths of sewage fungus. The leachate from the Mavallipura illegal solid waste dump near Bangalore is allowed to stagnate in a ditch next to the dump and slowly finds its way into surface and ground water aquifers. Over the years all drinking water sources in the vicinity have been adversely affected, and the threat looms large of contaminating the Arkavathy river, a major drinking water source of Bangalore **(ESG, 2011)**.

2.4 INTEGRATED SOLID WASTE MANAGEMENT (ISWM)

Proper municipal solid waste management (MSWM) involves the application of the principle of Integrated Solid Waste Management (ISWM) **(CPHEEO, 2016)**. ISWM is the application of suitable techniques, technologies and management systems covering all types of solid wastes from all sources to achieve the twin objectives of (a) waste reduction and (b) effective management of waste still produced after waste reduction. ISWM is a comprehensive waste prevention, recycling, processing and disposal program. An effective ISWM system considers how to prevent, recycle, and manage solid waste in ways that most effectively protect human health and the environment. It involves evaluating local needs and conditions, and then selecting and combining the most appropriate waste management activities for those conditions. The major ISWM activities are waste prevention, segregation, recycling and composting, incineration and subsequently disposal in properly designed, constructed, and managed landfills. An effective integrated solid waste management system depends upon the correlation between functional elements (generation, segregation, storage, collection, transportation, processing and disposal) and strategic aspects (social awareness, participation, technology, governance and financial resources). The strategic aspects provide strength to the ISWM system **(Gupta and Misra, 2014)**. With increasing population and changing lifestyles, there is continuous escalation in solid waste generation worldwide and the existing techniques and facilities are ineffective in managing the solid wastes especially in developing countries like India — an easily-implementable and economically feasible ISWM system that can effectively address and manage solid wastes is the need of the hour.

Recognizing this fact, the EPA has developed a national strategy for integrated solid waste management. The intent of this plan is to assist local communities in their decision making by encouraging those strategies that are the most environmentally acceptable. The EPA ISWM strategy suggests that the list of the most to least desirable solid waste management strategies should be (i) reducing the quantity of waste generated (ii) reusing the materials (iii) recycling and recovering the materials (iv) combusting for energy recovery (v) landfilling. That is, when an integrated solid waste management plan is implemented for a community, the first means of attacking the problem should be reducing the waste at the source. The action minimizes the impact of natural resource and energy reserves.

Reuse is the next most desirable activity, but this also has a minimal impact on natural resources and energy. Recycling is the third option, and should be undertaken when most of the waste reduction and reuse options have been implemented. Unfortunately, the EPA confuses recycling with recovery, and groups them together as meaning any technique that result in the diversion of waste. As previously defined, recycling is the collection and processing of the separated waste, ending up as new consumer product e.g. compost. Recovery is the separation of mixed waste, also with the end result of producing new raw materials for industry.

The fourth level of the ISWM plan is solid waste combustion, which really should include all methods of treatment. The idea is to take the solid waste stream and to transform it into a non polluting product. The conversion may be by combustion, but other thermal and chemical treatment methods may eventually prove just as effective. Finally, if all of the above techniques have been implemented and/or considered, and there is still waste left over (which there will be), the final solution is landfilling. At this time there really is no alternative to landfilling (except disposal in deep water - which is now illegal), and therefore, every community must develop some landfilling alternative.

2.5 OPTIMIZED MODEL OF INTEGRATED SOLID WASTE MANAGEMENT

Solid waste management is a multidisciplinary field requiring information about the physical, environmental, social, and economic implications of a SWM system. The ISWM approach is designed to minimise the initial generation of waste through source reduction, then through reusing and recycling to further reduce the volume of materials being sent to processing and landfills, compared to the conventional approach of simply focusing on disposal of solid waste. Systems analysis, a discipline that harmonizes these integrated solid waste management strategies, has been uniquely providing interdisciplinary support for decision making in this area. Systems engineering models and system assessment tools, both of which enrich the analytical framework of waste management, were designed specifically to handle particular types of problems.

Anderson (1968) was the first to propose a mathematical model to optimise the waste management system. His LP model considered only waste flows from transfer station to landfill sites and tends to minimise the partial costs involved in a SWM system. Since then, several researchers have developed solid waste management models as decision-support tools for processing technology selection, siting and sizing of waste processing facilities, vehicle or manpower management and overall system optimisation.

Different models of waste planning have been researched and applied in the SWM field in the following decades. The primary considerations involved are cost control, environmental sustainability and waste recycling. The techniques employed include linear programming, mixed integer linear programming i.e. MILP, multi-objective programming, nonlinear programming.

Linear programming is the most basic form of SWM modelling; the objective function is linear and the constraints comprising of equalities and inequalities are linear too. Cost is generally taken as the most appropriate objective function. The downside of LP models are that they may involve too many variables and constraints which affect computational time. In *mixed integer linear programming* models, some of the variables are constrained to be integers. *Inexact analysis* often treats the uncertain parameters as intervals with known lower and upper bounds and unclear distributions.

Daskalopoulos et al. (1998) had developed a MILP model for the management of different MSW streams, taking into account their rates and compositions, as well as their adverse environmental impacts. Using this model, the authors have identified optimal combination of technologies for handling, treatment and disposal of MSW in a more economical and environmental-friendly way. In this model, the optimal MSW flows to different types of treatment alternatives are determined by minimising a linear cost function. Environmental costs were calculated based on greenhouse gas emissions and their global warming potentials. However, the model does not cover collection and transportation costs, which accounts for nearly 70-80% of total MSW management costs in developing economies.

Badran and El-Hagar (2006) had proposed a MILP model for optimal management of municipal solid waste at Port Said, Egypt. The idea is to choose a combination of collection stations from the possible locations in such a way as to minimise the daily transportation costs from the districts to the “collection stations”, and then from the collection stations to the composting plants and/or landfills. The constraints for the objective function (i.e. cost) are the capacity constraints for collection stations, composting plants and landfills. However, recycling, incineration and RDF plants as well as regulatory and environmental constraints have not been considered in this model.

Najm et al. (2002) had introduced optimisation techniques to design least cost solid waste management systems, considering variety of management processes. Their LP model accounts for solid waste generation rates, composition, collection, transportation, treatment, disposal as well as potential environmental impacts of various MSW management techniques. Environmental costs were determined based on the value that the society places on environmental damage which was assumed equal to the cost of abatement and remediation of potential pollution.

Costi et al. (2004) had proposed a mixed integer, non-linear decision model to plan the municipal solid waste management, defining the refuse flows that have to be sent to recycling /processing/ disposal units, suggesting the optimal number, the types and the siting of the plants. The objective function takes into account all possible economic costs, whereas constraints arise from minimum requirements for recycling, incineration process requirements, sanitary landfill conservation and mass balance. The model has been formulated considering stringent European legislation guidelines for MSW management concerning waste minimisation, recycling, energy and material recovery, and final disposal at landfill. Regulatory, technical and environmental constraints had been comprehensively covered in their model. The authors in their research had included waste flows from RDF-plant and stabilised organic matter treatment plant to incinerator. A very similar type of model was presented by **Fiorucci et al. (2003),** except that **Costi et al. (2004)** had incorporated the environmental impacts of solid waste management system as well in their model.

Rathi (2007) had developed a linear programming model to integrate different options and stakeholders involved in MSW management in Mumbai. Different economic and environmental costs associated with MSW management were considered. In the model, the author had taken into account community compost plants, mechanical aerobic compost plants and sanitary landfills as waste processing/disposal options while environmental costs were primarily taken from California Integrated Waste Management Board (1991) literature. Shortcomings in this model include non-consideration of waste-to-energy treatment plants and certain costs taken directly from foreign literature.

Rawal et al. (2012) had divided the study area into zones — each zone has a ward which is the ‘waste centre’ or ‘waste source’. They proposed a VRP (Vehicle Routing Problem) method that first minimised MSW collection vehicle routes. The optimised collection points were further utilised in the development of optimised model formulations. They compared two models — one, integer-linear (IL) programming program, where variables are the number of trucks and the other, mixed integer linear (MIL) program where variables are the amount of waste actually transported. However, in this model, stabilised organic material plant construction and operation cost and environmental costs have been excluded.

C.K.M. Lee et al. (2016) had developed a linear programming model to integrate different options and stakeholders involved in MSW management in Hong Kong. This mathematical model provide useful information for decision makers to select appropriate choices and save cost. In this model they consider municipal solid waste management in a holistic view and improve the utilization of waste management infrastructures. In this model they developed mixed integer programming for Hong Kong municipal solid waste management with adopting integer linear programming. The objective function was to minimal cost of for the municipal solid waste management system.

Chattopadhyay et al. (2018) had developed a liner programming model for MSW management in Kolkata. The author run the model in LINDO. In this model he had done various sensitive analysis. In this model they did not consider transfer station.

Paul et al. (2019) had developed a liner programming model for MSW management in Kolkata. They run the model in LINGO. In this model they consider transfer station. They find the landfill site location along with transfer station by GIS and run the model once with considering transfer station near the KMC boundary then again run it with considering transfer station far from KMC boundary. As a result they find that the cost was minimum when they consider transfer station near KMC boundary.

Although Paul et al. (2017) proposed a minimum cost of SWM with considering transfer station near KMC boundary. They had consider three number of landfill sites along with three dedicated transfer station transfer station. But in practical situation it is impossible to construct all the landfill sites along with transfer station at a time. For that case we have to know which landfill site along with is most essential for cost minimization. Based on that result we can suggest that this Landfill site along with transfer station will have to construct first. Besides in any accidental condition any of the three assumed landfill site may not function properly. In that case also we have to fix that problem according to the landfill site's importance. For that purpose we have to run the model again with various combination.

Although sufficient literature is available worldwide linking ISWM and operations research, yet not much work has been carried out in India in this field. Again, most of the ISWM mathematical models proposed in developed countries lacks in collection and transportation constraint details, although a major fraction of total SWM budget is spent on this.

From the foregoing discussion it is evident that waste generation is an integral consequence of human civilization and at present era as a result of exponential growth of population and civilization, huge generation of municipal solid waste (MSW) and its improper management, especially in developing countries, has become a life-threaten issue for the society. As the existing conventional MSW management is unable to satisfy the goal of sustainable development, integrated MSW management system is needed to achieve this goal. Thus, for proper implementation of an ISWM system, there is a need to formulate a mathematical model for the SWM of a municipality, taking into account waste generation rates, composition, segregation, transportation modes, recycling, processing techniques, revenues from waste processing — simulating actual waste management as closely as possible — this will help as a decision support tool to select the best-suited, optimised system from various sets of solutions.

3. OBJECTIVE AND SCOPE OF WORK

Objective of the present study is to develop a Linear Programming (LP) model for existing and proposed integrated municipal solid waste management system considering all operational constraint along with economic aspect. Study of this model on Kolkata perspective.

The study envisages to encompass the following aspects:

- Study of municipal solid waste management system — existing and integrated.
- Development of LP model of municipal solid waste management system.
- Validation and study of the model for existing situation– based on Kolkata solid waste management.
- Study of integrated solid waste management – based on Kolkata solid waste management.
- Comparison of result for different case studies.

4. SOLID WASTE MANAGEMENT SYSTEM IN KOLKATA

The city of Kolkata (formerly Calcutta) is more than 300 years old and it served as the capital of India during the British governance until 1911. Kolkata is the capital of the Indian state of West Bengal and is located on the east bank of River Hooghly; and is the main business, commercial, and financial hub of eastern India and the north-eastern states. Kolkata (latitude 22° 33′ North and longitude 88° 30′ East) has an area of about 187.33 sq. km and a population of about 10 million (including floating population). KMC is responsible for solid waste management within the city. KMC area comprises of 15 boroughs and 141 electoral wards (till June 2015); each borough consisting of a cluster of wards. Figure 4.1 shows the location of wards, boroughs, in Kolkata.

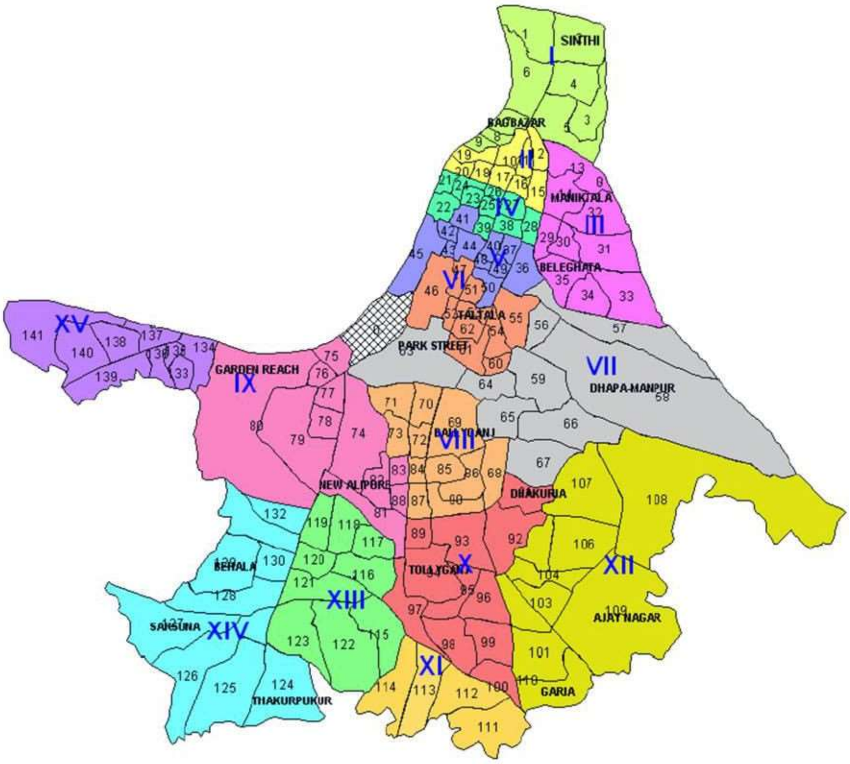

Figure 4.1 Map shows location of wards, boroughs in Kolkata

However, on 11th June, 2015, the KMC Mayoral Council passed a resolution to create a new Borough XVI with three wards from Joka and two wards each from two other boroughs. Borough-ward boundaries thus underwent changes in 2015 and KMC area increased to 200.71 km2 with the addition of Joka Gram Panchayats. Minor changes were accommodated in the fourth part of the thesis work; however Borough XVI has not been taken into account.

KMC area generates about 3000-3500 MT of waste per day at a rate of about 0.450 kg/capita/day (as per KMC records). Table 4.1, Table 4.2 and Table 4.3 illustrates the borough-wise waste generation rates (projected from KMC collection and transportation records), and waste composition and characterisation of KMC area.

Table 4.1 Garbage and silt/rubbish quantity generated in different boroughs in KMC area

Borough	Garbage (TPD)	Silt (TPD)
1	196.28	21.11
2	192.632	12.63
3	197.43	21.09
4	171.85	13.35
5	207.33	18.0
6	257.64	36.9
7	265.67	65.7
8	176.43	42.08
9	292.6	27.2
10	370.61	32.5
11	105.0	1.89
12	91.89	2.36
13	172.75	4.14
14	142.2	9.84
15	24.4	0.06

Table 4.2 Variation in MSW composition at Kolkata during 1970, 1995 and 2005 **(NEERI, 1995, 2005)**

Sl. No.	Parameters	1970	1995	2005
1	Biodegradable	40.36	44.29	50.56
2	Green coconut shells	4.95	8.51	4.5
3	Paper	3.17	4.64	6.07
4	Plastics	0.64	3.22	4.88
5	Metals	0.66	0.43	0.19
6	Glass & Crockery	0.38	1.72	0.34
7	Coal	6.08	3.10	-
8	Inert	40.76	26.82	29.6
9	Others*	3.00	7.27	3.86

All values are in percent by net weight

** Bio-resistant and synthetic material*

Table 4.3 Variations of MSW composition (Chemical Parameters) at Kolkata during 1970, 1995 & 2005 **(NEERI, 1995, 2005)**

Sl. No.	Parameter	1970	1995	2005
1	Moisture	42.84 %	61.57 %	46 %
2	pH	7.31	6.33	0.30-8.07
3	Loss of Ignition	35.24 %	46.78 %	38.53 %
4	Carbon	19.58 %	25.98 %	22.35 %
5	Nitrogen as N	0.55 %	0.88 %	0.76 %
6	Phosphorous as P_2O_5	0.57 %	0.58 %	0.77 %
7	Potassium as K_2O	0.40 %	0.93 %	0.52 %
8	C/N Ratio	35.60	29.53	31.81
9	LCV Kcal/Kg	549.32	648.91	1201

All values are in percent by dry weight basis except pH & LCV

In Kolkata, the major disposal ground is Dhapa (21.47 ha) located in the eastern side of the city and operational since 1981. It receives about 3000-3200 MT of solid waste per day. Another site at Garden Reach (3.52 ha) receives about 100-150 MT of solid waste per day. Both the sites practise open dumping, without any liner / leachate management facility or gas management system. Waste is simply spread at the landfilling sites by the bulldozers/dumpers without any compaction. Almost the entire collected untreated waste is dumped at Dhapa disposal site which is at an average distance of 10 kms from the collection points. In the absence of engineered landfilling, bulldozers are used at Dhapa to spread and level the garbage.

One major problem associated with open dumps is the infiltration of leachate into the surrounding environment and subsequent contamination of land and water. The quality of leachate, sampled from the existing MSW disposal site at Dhapa, showed that concentrations of solids, BOD, COD and chloride are much higher than those allowed for discharge into inland surface water (Das and Bhattacharya, 2013; Mandal, 2007). The concentration of toxic metals such as As, Hg, Pb, Cd, Cr, Cu, Zn, Ni and fluoride are reported to be lower than permissible limits for discharge into inland surface water. The quality of wastewater in the canals at Dhapa area shows that concentrations of total solids, BOD, COD and Cr are high. Similarly wetlands in Dhapa areas were found to have high BOD, COD values **(KEIP, 2005)**. A similar study conducted by Motling et al. (2013) found very high values of organic pollutants, COD, TDS, Fe2+, Cr, Zn, chloride and ammonical nitrogen. The Leachate Pollution Index (LPI) value of Kolkata landfill site at Dhapa was estimated and compared with leachate quality data of other metropolitan cities viz. Mumbai, Delhi, Chennai as available in literatures. It was found that LPI of the Kolkata landfill site is the highest compared to all other landfill sites of other metropolitan cities in India. A Kolkata Environmental Improvement Project (KEIP) study (2005) monitored the quality of groundwater during March-April 2004 at locations in and around Dhapa. The results showed persistent presence of phenolic compounds in Dhapa and its adjoining areas much above the desired limit; Pb, Fe and As were found slightly above the desired limit at certain locations; TDS, total hardness and alkalinity were also higher than permissible limit. All the above factors, coupled with the fact that landfill space at Dhapa has already exhausted, has prompted urban planners to search and develop a new engineered landfill (ELF) site at the earliest.

Management of solid waste is a major cost-intensive service. In Kolkata, a large part of the expenditure goes to payment of salaries of municipal staff, since sweeping and collection is done manually. Most of the expenditure is on waste collection (70-75%) and transportation (20-25%) and only a nominal amount (4-6%) is spent on the disposal system. Only a small percentage goes towards capital expenditure or improvements to the three systems **(Chattopadhyay et al., 2009)**. Despite 70%-75% of SWM budget being allocated for collection and transportation, collection efficiency is around 70-80% for the registered residents and around 20% for slum population **(Hazra and Goel, 2009)**.

KMC had allocated Rs.1590.35 million on SWM for 2007-2008, which is 13.75% of its total annual budget. The budget allocation is low compared to other Indian cities like Asansol (44.7%), Agra (30.39%), Patna (29.36%) and Varanasi (27.8%). Estimates of expenditure on MSWM ranged from Rs. 258 to Rs.431 per capita annually in various Indian cities during 2007-2008. During that same time, KMC spent Rs. 265 per capita on MSWM, Rs. 243.71 on treatment and water supply and Rs. 141.43 on wastewater treatment **(Hazra and Goel, 2009)**. Despite this expenditure, the level of service has not been satisfactory.

Considering putrescible nature of waste, collection and disposal has to be done on a daily basis. Collection, transportation and disposal of MSW in Kolkata encompass an extremely complex set of operations. In the early morning hours, conservancy staffs arrive at their assigned areas with handcarts and blow their whistles requesting residents to deposit wastes in their handcarts. The handcarts are then taken to the nearby vat/container locations and MSW is transferred to the vats/container locations. During 2009-2010, total collection points in the city was around 650 with 365 mild-steel MS skips/containers, 20 direct loading, and 265 open vat point. Skips/Containers are of two sizes — Normal (4.5 m3) and Big (7 m3). Collection, transportation and disposal are the most pressing problems of the city today. In many cases, household wastes are littered in and around bins, some of the bins overflowing due to insufficient capacity and/or infrequent collection. Cleaning of streets and waste collection is done almost regularly in the core KMC area, but in the adjoining areas there is a dearth of conservancy workers and handcarts.

As of now, there is no source segregation system in KMC area. On average, 25.3% of household waste and 51% of commercial wastes in Kolkata are recyclable **(KEIP, 2003)**. Proper sorting and segregation at source may lead to increase in collection efficiency. About 10% of disposed waste is recycled by the informal sector i.e. rag-pickers who carry out their activities at vat points and landfill sites in an unorganised, unhygienic way, without any government support.

For transporting waste from vat points to dumpsite, KMC uses its own departmental vehicles and privately owned hired vehicles. KMC waste transport system utilises private owned lorries to transport 55% to 60% of the daily generated garbage and entire amount of the silt/rubbish. Haulage capacities of these hired vehicles are 4 MT for manually loaded and 7 MT for payloader loaded garbage transportation and 6 MT for manually loaded and 9 MT for payloader loaded silt/rubbish transportation. Each lorry visits open vat location(s) and after their haulage capacity is exceeded, the vehicles proceed to the dumping ground. The remaining 40% of MSW (garbage only) is transported by KMC owned departmental vehicles. Till 2009-2010, the departmental vehicles were of the four following types:

- Container carrying vehicles (Dumper-Placers): One Dumper-Placer (DP) can hoist and transport only one skip/container at a time to the disposal ground. KMC currently uses two types on skips— 4.5 m3 size (1.75 MT haulage capacity DP) and 7 m3 size (2 MT haulage capacity DP).

- Manually loaded Tipper Trucks (8 m3): They haul around 3 MT of MSW to the Dhapa landfill site from various open vats/open dumping areas in one trip.

- Payloader loaded Tipper Trucks (11 m3): They haul around 7 MT of MSW in one single trip to Dhapa. These vehicles collect MSW from various open vats and after collecting around 7 MT of wastes, it proceeds to Dhapa.

Of late, KMC has embarked on modernising its departmental waste transportation fleet by purchasing compactors and the transportation system has undergone remarkable change over the last few years. KMC currently uses the following six types of departmental conservancy vehicles for waste transportation:

- Container carrying vehicles (Dumper-Placers): One Dumper-Placer (DP) can hoist and transport only one skip/container at a time to the disposal ground. KMC currently uses two types on skips— 4.5 m3 size (1.75 MT haulage capacity DP) and 7 m3 size (2 MT haulage capacity DP).

- Payloader loaded Tipper Trucks (11m3): These trucks haul around 7.0 MT of MSW in one single trip to Dhapa.

- Stationary compactor-cum-hook loader combination (10.5m3/9MT): KMC is purchasing 198 stationary compactors to be placed at 85 compactor stations. These compactors reduce 30% waste volume by applying 140 bar pressure. KMC is also acquiring 54 hook loaders, to haul these stationary compactors to Dhapa. Each hook loader can haul one stationary compactor at a time.

- Movable compactors (14m3/10MT): KMC is purchasing 64 numbers of 14m3 capacity movable compactors. It takes waste from six 4.5m3 skips (or from handcarts), compact it at 140 bar pressure, and hauls waste to the landfill site.

- Movable compactors (8m3/7MT): KMC is purchasing 4 numbers of 8m3 capacity movable compactors. These smaller sized compactors can manoeuvre narrow streets and lanes.

However as the departmental vehicle fleet underwent modernisation, modifications were incorporated for the modeling work in Chapter 6. Similarly in Chapter 6, for hired vehicles, haulage capacity has been taken as 7 MT for garbage transportation and 9 MT for silt transportation, assuming they are all payloader loaded.

Most of the vehicles (especially hired vehicles) used for secondary transportation of waste are old — this increases operation and maintenance costs, reduces efficiency and causes noise and air pollution. KMC departmental vehicles are inadequate in number, and around 50%-60% of its fleet remains operational at any point of time. Presently, collection and transfer of MSW in the KMC area is conducted in an ad hoc basis. Solid waste vehicles are assigned to neighbourhoods without any systematic demand analysis. Route selection is left to the drivers and each vehicle collects solid waste along its route until maximum capacity is reached; it then goes to the disposal site to dump the waste. The empty vehicle then returns to its route and continues collection for the next waste load. Since the route is not planned for avoiding traffic, vehicles travel extra distance or spend more time of the road, increasing fuel and operating cost.

Currently, there is no incinerator/RDF plant in Kolkata. Neither waste segregation/sorting exist, nor is engineered landfilling practised. A 700 MT/d compost plant running on PPP (public-private partnership) model at Dhapa disposal ground processes only 150 MT/d when it is operational. The average density of waste in KMC area is quite high (~600 kg/m3) — this makes compaction largely unnecessary. Given the high biodegradable fraction (50.56%), high C/N ratio (31.81%) and high moisture content (46%) in waste, composting may prove to be cost effective. In a feasibility study of a WTE project with MSW in Kolkata, mass burn technology has been considered, instead of more advanced and costly systems such as gasification, pyrolysis and plasma-arc. The possibility of RDF fuel production was discarded due to non-availability of local market. However, to make mass burn incineration or any other processing project successful, sorting/segregation of waste streams is a prerequisite. A source segregation project was attempted in Garden Reach borough XV during 2006, but failed due to non-disbursal of funds by KMC (Times of India, 2015). KMC budget for financial year 2013-14 proposed source segregation of biodegradable and non-biodegradable wastes in ward numbers 33, 47, 64, 103, 110, 115, 130. Recognising the importance of source segregation in an ISWM system, KMC has thus initiated steps for the source-segregation of wastes.

For successful implementation of Municipal Solid Waste Management Rules, 2000, KMC needs to initiate ISWM system by adhering to the ISWM ‘hierarchy of waste management’. With the Ministry of Urban Development, Govt. of India promoting and funding “Swachh Bharat Mission” in a big way, one expects SWM will be managed in a more modern and scientific way in very near future. “Swachh Bharat Mission” envisages capacity augmentation of urban local bodies (ULBs), 100% collection, transportation and processing of solid waste and public-private partnership (PPP) in setting up and operation of waste processing units. This will require re-organising and overhauling the entire SWM system. The thesis work proposes an ISWM optimisation model to improve MSW management system in Indian cities in general and KMC area in particular. Although there has been two previous MSWM modeling on Kolkata, India — Chattopadhyay (2018) and Paul (2019) had proposed MSW management models — but further studies have to be done on it.

5. MODEL DEVELOPMENT AND METHODOLOGY

Now a days the conventional system deals with the storage, collection, transportation and disposal of wastes which are the responsibility of the municipal authorities. Re-use, recycling, waste minimization, engineered landfill, waste to energy etc. do not receive so much attention. In many cities, the municipal or contracted system only handles a minor fraction of the potential waste generated by residential, industrial, commercial, institutions etc. Municipalities worldwide are facing day to day increased difficulties in managing their huge waste effectively and economically. Increased waste quantities, reducing urban space for dumping/landfilling, growing public environmental awareness, stringent technical requirements on management alternatives, as well as waste prevention and recycling goals demands an integrated solid waste management (ISWM) system involving a combination best available techniques and programs to manage the MSW **(Najm et al., 2002)**. Among the large number of available options for SWM and the inter-relationships, identifying SWM strategies that satisfy economic and environmental objectives is a complex task. Decision makers need to formulate solutions that consider multiple goals and strategies.

It can be inferred from the literature that no single methodology can solve the problem of waste management. There is a need to combine different methods and stakeholders in such a way that it can minimize environmental and social costs associated with waste management. This chapter develops a mathematical model for municipal SWM, taking into account waste generation rates, recycling and reusing, composition, transportation modes, processing techniques, revenues from waste processing, landfilling, operational constraints along with economics and simulating solid waste management as closely as possible. The integrated approach to SWM was a response to failure of the conventional approach in developed countries. ISWM includes preventing waste, minimizing the initial generation of materials through source reduction, reusing and recycling and composting to reduce the volume of materials being sent to landfills or incineration.

The purpose of the model is to assist in selecting strategies that minimize the cost of waste collection, storage, transportation, operation of recycling, treatment and disposal subject to physical constraints. It reduces the adverse environmental impact of the SWM. The proposed model includes the revenues produced by the sale of recyclable materials, sale of composting materials, sale of electricity generated by the facility. For driving the model we have to minimize the secondary collection and transportation, operation of treatment and disposal, revenues from recycling, composting and incinerator. To consider all conflicting objectives, the modelling of an SWM system demand multi-objective decision concepts and techniques. However, the multi objective nature of the decision problem can be simplified by considering a single optimisation objective of minimising total cost, and transforming all other objectives into constraints. The constraints include those linking waste flows and its mass balance, recycle amount, processing plants operation and capacity, landfill operation and capacity, transport vehicle operation and capacity, number of trips, etc. The optimisation problem can be described as follows: given the quantities of waste generated at the sources (borough centers are taken as waste sources); the number, types, capacities and operating cost of conservancy vehicles; the location, operating cost and capacities of existing and proposed facilities; evaluate how the waste should be collected, transported, recycled, processed and disposed off, so as to minimise the overall cost. The model is validated with the existing datasets of SWM system of Kolkata city of 2007 and further the model is extended for the proposed integrated waste management system to explore its effect on cost and various operational parameters. This will help to predict the outcome of ISWM which facilitates for environmental policy making in future SWM. Here in this model also we consider transfer station which is placed at the middle between borough and dump site/landfill.

5.1 MODEL DEVELOPMENT

Integrated Solid Waste Management (ISWM) is considered for an Indian city with proper segregation and treatment along with the following basic considerations:

- The city is divided into zones for each disposal site.
- Borough centres have been assumed as the waste generation points.
- In integrated solid waste management segregation at source is considered. Two bin systems - one for biodegradable waste and the other for non-biodegradable waste is assumed.
- Garbage enters central/intermediate sorter and subsequently to the different processing plants, while silt/rubbish goes straight to landfill without sorting or processing.
- Intermediate or central sorting facility is considered for sorting the recyclable, biodegradable, combustible and inert from garbage.
- Recyclable should be sent to the common recycling facilities and revenue will be generated by selling the recyclables.
- Average waste generation data of the boroughs of the concerned municipality is considered for running the model.
- The municipality uses departmental and hired vehicles to transport wastes. Departmental vehicles carry garbage only while hired vehicles carry both garbage and silt/rubbish. Silt/rubbish and garbage are collected separately. There are different types of departmental vehicles but only one type of hired vehicle.
- Minimum and maximum number of trips of departmental vehicles as well as for hired vehicles is fixed for each zone.
- The departmental vehicles will have to undertake certain minimum number of trips per day as they are salaried staff of municipality.
- The drivers and helpers of departmental vehicles will be paid incentives if they carry out more than minimum number of trips. Hired vehicles will be paid on the basis of tonnage of waste transportation to the different destination.

- To make the model flexible and more realistic, borough-wise minimum and maximum garbage carrying range (in fraction) for both departmental and hired vehicles is considered based on variation of actual waste carried by different types of vehicles from different boroughs.
- Garbage enters central/intermediate sorter and subsequently to the different processing plants, while silt/rubbish goes straight to landfill without sorting or processing.
- Treatment and disposal of garbage will be done as per its characteristics — like high calorific value of waste may go for incineration and biodegradable organic waste for composting. In all treatment techniques, pre-sorting facilities will be there for further segregating the inert and recyclable from the waste coming from central sorter. Inert, process rejects and residues from treatment plant will go to engineered landfill.
- The operational cost of the incinerator includes the operation (including pre-sorter) and maintenance cost of incinerator and the transportation cost of combustible waste from the sorting facility to the incinerator.
- The operational cost of the composting plant includes cost of operation (including pre-sorter) and maintenance of composting plant and transportation cost from the central sorting facility to composting plant.
- Environmental costs of the processing plants and landfilling has not been taken into account.
- The model excludes the cost of collection of waste by municipal staff from households to vat/container location.

Based on the above assumptions, a material flow chart (Figure 5.1) for every 100 MT of garbage generated at source has been developed. Out of this 100 MT MSW generated, it is assumed that 5 MT of waste components is segregated and recycled at household level; the rest 95 MT enters the central sorting facility of a disposal site and is subjected to different processing techniques present within that disposal site. It is assumed that the city has different engineered landfill sites. Since western site of Kolkata is extended up to river Ganga and on the other bank Howrah city is located with their solid waste management system so no solid waste disposal facilities at western side is considered. In this problem we assumed that the city has *D* numbers of disposal sites at different locations. Each disposal site *d* has one central sorting station, one recycling facility, one incinerator, one composting facility and one landfill. From the central sorting facility, one stream is recycled to recycling facility, while other streams may go to incinerator, composting plant, or landfill as per the material flow chart illustrated in the Figure 5.1. The incinerator and composting unit has pre-sorting units attached to them, so as to increase the efficiency of these processes. From these pre-sorting units, a small recyclable fraction may be dispatched to recycling facility while the inert fraction may be taken directly to landfill.

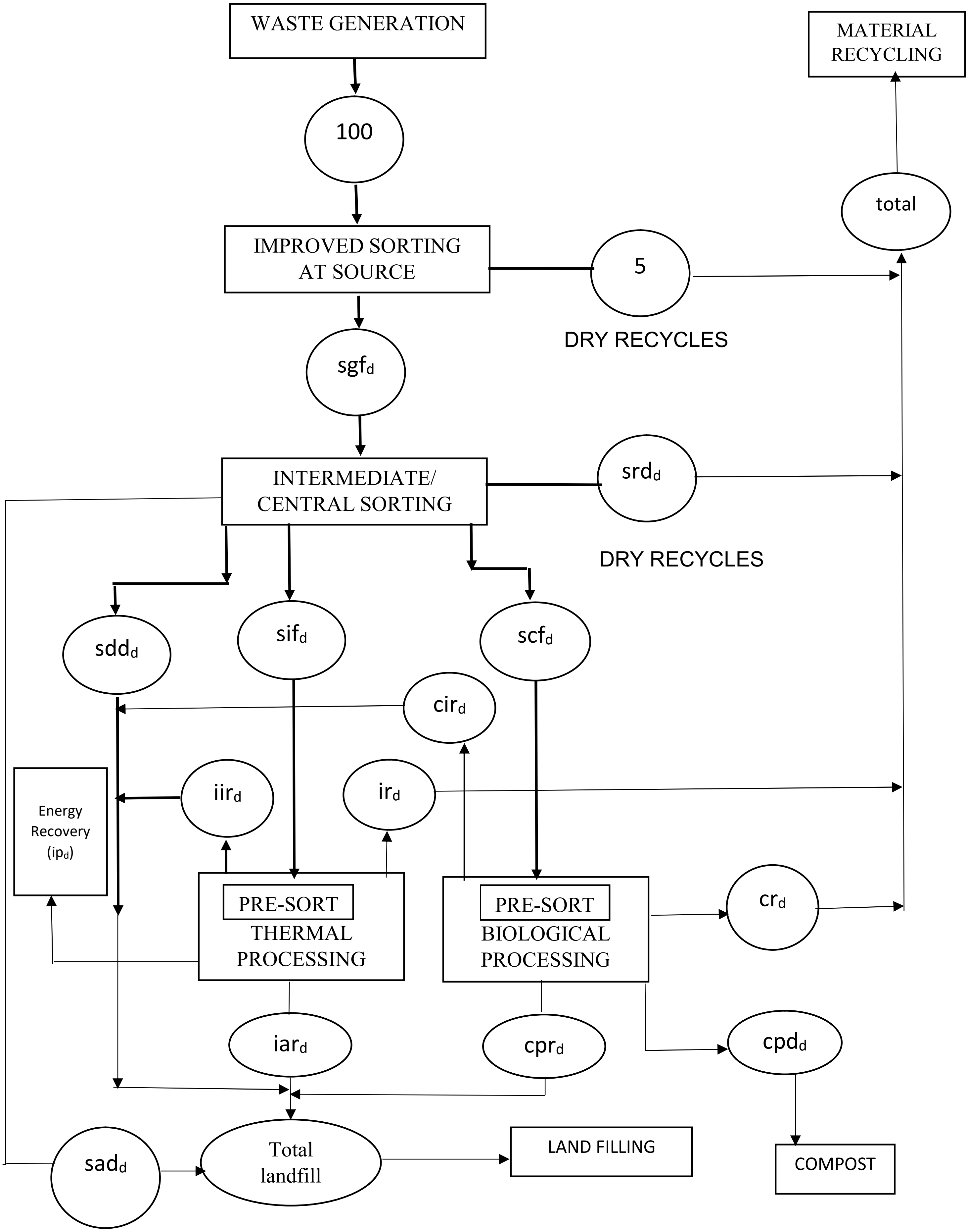

Figure 5.1 Materials flow chart for garbage at a disposal site

Parameter definition:

Indices:

BB	Total number of boroughs. For KMC's case, BB = 15
D	Total number of disposal sites. For KMC's case, D =3.
DD	Total number of departmental vehicles types. For KMC's case, DD= 6.
HH	Total number of hired vehicles types. There is only one type of hired vehicle in KMC i.e. HH = 1.
Z	Total number of zones associated with each disposal site *d*. In KMC's case, Z = 2.

bb	Index for boroughs (1..BB)
d	Index for disposal site (1..D)
dd	Index for departmental vehicle (1..DD)
hh	Index for hired vehicle
z	Index for zones associated with a particular disposal site *d* (1..Z)

Input data in the form of matrices:

bb_wg_{bb}	Amount of garbage generated in borough *bb*, MT. (BB × 1)matrix.
bb_ws_{bb}	Amount of silt generated in borough *bb*, MT. (BB × 1) matrix.
$bb\_fgddmax_{bb,dd}$	Maximum fraction of garbage transported by *dd* type departmental vehicles from borough *bb*. (BB × DD) matrix.
$bb\_fgddmin_{bb,dd}$	Minimum fraction of garbage transported by *dd* type departmental vehicles from borough *bb*. (BB × DD) matrix.
$bb\_fghhmax_{bb}$	Maximum fraction of garbage transported by hired vehicles *hh* from borough *bb*. (BB × HH) matrix.
$bb\_fghhmin_{bb}$	Minimum fraction of garbage transported by hired vehicles *hh* from borough *bb*. (BB × HH) matrix.
ics_ry_{d}	Recyclable fraction of solid waste coming out from sorter at disposal site*d*. (D × 1) matrix.
ics_ddy_{d}	Direct dumpable fraction of solid waste coming out from sorter at disposal site *d*. (D × 1) matrix.
$ics\_maxcomp_{d}$	Compostable fraction of solid waste coming out from sorter at disposal site*d*. (D × 1) matrix.

$ics\_maxinci_d$	Incinerable fraction of solid waste coming out from sorter at disposal site*d*. (D × 1) matrix.
ics_capmax_d	Maximum capacity of the central sorting facility at a disposal site *d*, MT. (D × 1) matrix.
ics_capmin_d	Minimum capacity of the central sorting facility at a disposal site *d*, MT. (D × 1) matrix.
ics_adc_d	Per ton cost of additional dumping from sorter to landfill at *d*, Rs/MT. (D × 1) matrix.
ics_rc_d	Cost of transporting recyclable material segregated from the sorter at disposal site *d* to recycling facility, Rs/MT. (D × 1) matrix.
ics_rrd	Revenue earned by selling per ton of recyclable materials generated from the sorting station attached to disposal site *d*, Rs/MT. (D × 1) matrix.
$ics\_sortcost_d$	Operational cost of sorting per ton of solid waste for the central sorting station associated with the disposal site *d*, Rs/MT. (D × 1) matrix.
ip_ry_d	Recyclable fraction of waste coming out from incinerator pre-sorter at *d*. (D × 1) matrix.
ip_iry_d	Incineration inorganic reject fraction coming out from incinerator pre-sorter at disposal site *d*. (D × 1) matrix.
ip_ay_d	Incineration ash reject (incineration product) fraction coming out from the incinerator at disposal site *d*. (D × 1) matrix.
fd	kWh units of electricity generated by processing unit MT of MSW in incinerator at disposal site *d*. (D × 1) matrix.
ip_capmax_d	Maximum capacity of the incinerator at a disposal site *d*, MT. (D × 1) matrix.
ip_capmin_d	Minimum capacity of the incinerator at a disposal site *d*, MT. (D × 1) matrix.
ip_ac_d	Per ton cost of transporting incinerator ash reject portion from pre-sorter to landfill for a particular disposal site *d*, Rs/MT. (D × 1) matrix.
ip_irc_d	Transportation cost of transferring inorganic rejects from incinerator pre-sorter to landfill attached to disposal site *d*, Rs/MT.(D × 1) matrix.
ip_rc_d	Per ton transportation cost of the recyclables from the incinerator pre-sorter attached to the disposal site *d*, to the recycling facility at*d*, in Rs/MT. (D × 1) matrix.

ip_rev_d	Revenue that can be earned in selling one kWh unit of electricity generated from the incinerator associated with disposal site *d*,Rs/kWh. (D × 1) matrix.
ip_rr_d	Revenues earned from selling recyclable materials sorted out from incinerator pre-sorter at a disposal site *d*, Rs/MT. (D × 1) matrix.
ip_opcost_d	Operational cost of the incinerator at disposal site *d*, Rs/MT. It includes the construction and operational cost of incinerator and the transportation cost of incinerable waste from the sorting facility to the incinerator. (D × 1) matrix.
cp_ry_d	Recyclable fraction of waste coming out from composting plant pre-sorter at *d*. (D × 1) matrix.
cp_iry_d	Composting inorganic reject fraction coming out from the composting plant pre-sorter, at disposal site *d*. (D × 1) matrix.
cp_prdy_d	Composting product (compost) to composting plant feed ratio at a disposal site *d*. (D × 1) matrix.
cp_pry_d	Compost plant process rejects fraction coming out from the composting plant at disposal site *d*. (D × 1) matrix.
cp_capmax_d	Maximum capacity of the composting plant at a disposal site *d*, MT. (D × 1) matrix.
cp_capmin_d	Minimum capacity of the composting plant at a disposal site *d*, MT. (D × 1) matrix.
cp_irc_d	Transportation cost of inorganic rejects from composting pre-sorter to landfill at *d* on a per ton basis, Rs/MT. (D × 1) matrix.
cp_prc_d	Transportation cost of composting process rejects from composting plant pre-sorter to the landfill at disposal site *d*, Rs/MT. (D × 1)matrix.
cp_prdc_d	Selling price of the compost, Rs/ ton for a disposal site *d*. (D × 1) matrix.
cp_rc_d	Per ton transportation cost of recyclables from composting plant pre-sorter for a particular disposal site *d* to recycling facility at *d*, Rs/MT. (D × 1) matrix.
cp_rr_d	Revenues earned from selling recyclable materials sorted out from composting pre-sorter at a disposal site *d*, Rs/MT.(D × 1) matrix.

cp_opcost_d	Per ton operational cost of the composting plant including cost of construction and operation of composting plant and transportation cost from the central sorting facility to composting plant, Rs/MT. (D × 1) matrix.
$lfcapmax_d$	Maximum capacity of the landfill at disposal site *d*, MT. (D × 1) matrix.
lfc_d	Landfilling cost in Rs/MT of solid waste for the landfilling site associated with a disposal site *d*. It includes cost of land, liner, cover material, leachate collection and treatment cost. (D × 1) matrix.
dd_cap_{dd}	Average waste carrying capacity of a *dd* type of vehicle, MT. (DD × 1) matrix.
hhg_cap	Average garbage carrying capacity for hired vehicle *hh*, MT. (HH × 1) matrix.
hhs_cap	Average silt carrying capacity for hired vehicle *hh*, MT. (HH × 1)matrix.
cap_truck	Payload capacity of a heavy duty truck, MT.
$bb\_fc_{bb,d,dd}$	Average fuel cost for transporting per ton waste from borough *bb* to disposal site *d* by a *dd* type vehicle, Rs/MT. (BB × D × DD)matrix.
fc_t_d	Fuel cost per ton of waste transported by heavy duty trucks from transfer station associated with disposal site *d* to disposal site *d*, Rs/MT. (D × 1) matrix
$bb\_hcg_{bb,d}$	Per ton transportation cost of garbage from borough *bb* center to disposal site *d* for a hired vehicle, Rs./MT. (BB × D) matrix.
$bb\_hcs_{bb,d}$	Per ton transportation cost of silt from borough *bb* center to disposal site *d* for a hired vehicle, Rs./MT. (BB × D) matrix.
dd_fc_{dd}	Fixed running cost for each *dd* type departmental vehicle, Rs. (DD× 1) matrix
dd_ic_{dd}	Fixed idle cost for each *dd* type departmental vehicle, Rs. (DD ×1) matrix.
dd_na_{dd}	Total number of *dd* type departmental vehicles running.(DD × 1)matrix.
dd_no_{dd}	Total number of *dd* type vehicles in KMC fleet. (DD × 1) matrix.
t_rc	Fixed running cost per heavy duty truck, Rs.
t_ic	Fixed idle cost per heavy duty truck, Rs.

t_na	Number of heavy duty trucks actually running considering all the three disposal sites.
t_no	Total number of heavy duty trucks considering all the three disposal sites.
$trips\_truck_d$	Maximum number of trips each heavy duty truck associated with disposal site (and transfer station) *d* is required to make. (D × 1) matrix.
$r_{inc,dd}$	Rate of incentive (per extra ton basis) to be paid to the driver and helper of a *dd* type vehicle for transporting waste over and above the minimum trips, Rs/MT. (DD × 1) matrix.
$zz\_maxtrip_{dd,d,z}$	Maximum number of trips that a *dd* type departmental vehicle isallowed to undertake in zone *z* of disposal site *d*. (DD × D × Z)matrix.
$zz\_mintrip_{dd,d,z}$	Minimum number of trips that a *dd* type departmental vehicle has to undertake in zone *z* of disposal site *d*. (DD × D × Z) matrix.
$maxzz\_maxtrip_{dd}$	Maximum value of zz_maxtripdd,d,z for a particular *dd* type vehicle, considering all disposal sites *d*. (DD × 1) matrix.
$minzz\_mintrip_{dd}$	Minimum value of zz_mintripdd,d,z for a particular *dd* type vehicle, considering all disposal sites *d*. (DD × 1) matrix.

Variables:

CTCI	Total cost of incineration, in Rs.
CTCS	Total cost for sorting operation at central sorter, in Rs
CINCENT	Total incentive payable to KMC departmental vehicle drivers and helpers in case they run trips more than their minimum requisite number of trips, Rs.
CTCC	Total cost of composting, in Rs.
CTCX	Total landfilling cost, in Rs.
CTRANSP	Total cost of transportation of waste to all the disposal sites, in Rs.
CTREVC	Total revenue generated by selling compost, in Rs.
CTREVI	Total revenue generated by selling electricity generated from incinerator**,** in Rs.
CTREVR	Total revenue generated by selling recyclable materials from recycling facility, in Rs.

$qg_{bb,d,dd}$	Quantity of garbage transported from borough bb centre to disposal site d by dd type departmental vehicle, MT.
$qhhg_{bb,d}$	Quantity of garbage transported from a particular borough bb center to a disposal site d by a hired vehicle hh, MT.
$qhhs_{bb,d}$	Quantity of silt transported from a particular borough center bb to a disposal site d by a hired vehicle hh, MT.
sgf_d	Feed to sorting station associated with disposal site d, MT.
sr_d	Amount of recyclable material segregated from the solid waste feed at the central sorting station associated with disposal site d, MT.
sad_d	Additional amount of waste to be transferred directly from the sorting facility (after sorting but without any processing) to the landfill in case of emergency, MT. This value was equated to zero under normal circumstances.
sdd_d	Direct dumpable portion of waste stream (consisting of inert) that is directly taken to landfill bypassing sorter, for a disposal site d, MT
scf_d	Feed entering the composting plant from sorter at a disposal site d,MT.
sif_d	Feed from sorter to incinerator associated with disposal site d, MT.
ir_d	Recyclable portion sorted out from incinerator pre-sorter and dispatched to the recycling facility, MT.
iir_d	Inorganic reject portion separated from the incinerator pre-sorter and sent directly to landfill at a disposal site d, MT.
iar_d	Amount of incinerator ash products being transported from the incinerator to the landfill site, MT.
ip_d	Total kWh units of electricity generated by incinerator at d.
cr_d	Amount of waste recycled from the composting plant pre-sorter to the recycling facility related to disposal site d, MT.
cir_d	Inorganic reject amount transported from composting plant pre-sorter to the landfill for a particular disposal site d, MT.
cpd_d	Compost produced in the composting plant at the disposal site d,MT.
cpr_d	Composting process reject amount at a disposal site d, MT.
xf_d	Amount of waste being disposed off in the landfill associated with disposal site d, MT.
xfg_d	Total amounts of garbage transported to landfill at a disposal site d, MT.
$xsilt_d$	Total amounts of silt transported to landfill at a disposal site d, MT.
$xfrj_d$	Quantity of rejects from different processing methods like incineration

	inorganic reject, incineration ash, composting inorganic reject and composting process reject transferred to landfill at *d*, MT.
$at_{dd,d,z}$	Actual number of trips made by *dd* type departmental vehicle to a zone *z* of a disposal site *d*.
$athhg_{d,z}$	Actual number of trips made by hired vehicles *hh* in a zone *z* of a disposal site *d* for collection of garbage.
$athhs_{d,z}$	Actual number of trips made by hired vehicles *hh* in a zone *z* of a disposal site *d* for collection of silt.
$dg_{dd,d,z}$	Amount of garbage transported by *dd* type departmental vehicle to a disposal site *d* from zone *z* of *d*, MT.
$dghh_{d,z}$	Amount of garbage transported by hired vehicle *hh* to disposal site *d* from zone *z* of *d*, MT.
$dshh_{d,z}$	Amount of silt transported by hired vehicle *hh* to disposal site *d* from zone *z* of *d*, MT.
$ctcdd_{dd}$	Waste (garbage only) transportation cost by *dd* type departmental vehicles, Rs.
ctchh	Total cost of transportation of solid waste (garbage and silt/rubbish) by hired vehicles, Rs.
ctcghh	Total garbage transportation cost by hired vehicles from borough centers to disposal sites, Rs.
ctcshh	Total silt transportation cost by hired vehicles from borough centers to disposal sites, Rs.
$cfueldd_{dd}$	Cost of fuel incurred by *dd* type departmental vehicles for waste transportation, Rs.
$cfxdrdd_{dd}$	Total fixed cost for running *dd* type departmental vehicles, Rs.
$cfxdidd_{dd}$	Total fixed cost for idle *dd* type departmental vehicles, Rs.
cfueltruckstot	Fuel cost of the heavy duty trucks used for transporting dumpable waste from transfer station to disposal site landfills, Rs.
cfxdrtruckstot	Fixed running cost of the heavy duty trucks, Rs.
cfxditruckstot	Fixed idle cost of the heavy duty trucks, Rs.
$cinc_{dd}$	Amount of incentive (in Rs.) to be paid to a *dd*-type vehicle for transporting waste more than the minimum stipulated number of trps.
ctctrucks	Total cost of transporting dumpable waste from transfer station to the disposal site landfills by the heavy duty trucks, Rs.
no_trucks_{d}	Number of trucks associated with disposal site (and transfer station) *d*.

It is required to minimise the total cost of solid waste management. The objective function, taken as the total cost of solid waste management, may be expressed as:

Objective function = Cost of transportation + Incentive cost + Sorting cost + Incineration cost + Composting cost + Landfilling cost − Revenue earned from recycling − Revenue earned from composting − Revenue earned from incineration

$$\textit{Objective function} = CTRANSP + CINCENT + CTCS + CTCI + CTCC + CTCX - CTREVR - CTREVC - CTREVI \tag{1}$$

CTRANSP is the total cost of transportation of solid waste to all the three disposal sites. *CINCENT* is the incentive cost payable to the municipality departmental vehicle drivers and helpers in case they run trips more than their minimum number of trips. It is paid on the basis of per ton of waste transported to the disposal sites over and above the minimum trips. *CTCS*, *CTCI*, *CTCC*, *CTCX* are the total sorting cost, incineration cost, composting cost and landfilling cost for all disposal sites *d*; *CTREVR* is the total revenue generated by selling recyclable materials from recycling facility for all disposal sites *d*. *CTREVC*, *CTREVI* are the revenues generated by selling compost and electricity from composting plant and incinerator for all disposal sites *d*.

Based on average waste actually carried by different types of vehicles from different boroughs, borough-wise minimum and maximum garbage carrying range (in fraction) for both departmental and hired vehicles need to be fixed. This makes the model flexible and more realistic. The data is being used to set the following waste transportation constraints.

Garbage balance at a particular borough *bb*:

$$\sum_{d=1}^{D} \sum_{dd=1}^{DD} qg_{bb,d,dd} + \sum_{d=1}^{D} qhhg_{bb,d} = bb\_wg_{bb} \qquad \vee bb=1,2,\ldots,BB \tag{2}$$

$qg_{bb,d,dd}$ is the quantity of garbage transported from borough *bb* centre to disposal site *d* by *dd* type vehicles. $qhhg_{bb,d}$ is the quantity of garbage transported from a particular borough *bb* center to a disposal site *d* by a hired vehicle. bb_wg_{bb} is the amount of garbage generated in borough *bb*.

Silt/Rubbish balance at a particular borough *bb*:

$$\sum_{d=1}^{D} qhhs_{bb,d} = bb\_ws_{bb} \qquad \vee bb=1,2,\ldots,BB \tag{3}$$

$qhhs_{bb,d}$ is the quantity of silt transported from a particular borough center *bb* to a disposal site *d* by a hired vehicle. bb_ws_{bb} is the amount of silt generated at a borough *bb*.

Maximum amount of garbage dispatched from borough *bb* centre by *dd* type vehicle:

$$\sum_{d=1}^{D} qg_{bb,d,dd} \le bb\_wg_{bb} \times bb\_fgddmax_{bb,dd} \qquad \vee\ bb=1,2,\ldots,BB \quad \vee\ dd=1,2,..,DD \quad (4)$$

$\mathrm{bb\_fgddmax}_{\mathrm{bb,dd}}$ is the maximum fraction of garbage from *bb* borough that is transported by *dd* type departmental vehicles.

Maximum amount of garbage dispatched from borough *bb* by hired vehicles *hh*:

$$\sum_{d=1}^{D} qhhg_{bb,d} \le bb\_wg_{bb} \times bb\_fghhmax_{bb} \qquad \vee\ bb=1,2,\ldots,BB \quad (5)$$

$\mathrm{bb\_fghhmax}_{\mathrm{bb}}$ is the maximum fraction of garbage from *bb* borough that is transported by hired vehicles *hh*.

Minimum amount of garbage dispatched from borough *bb* by *dd* type departmental vehicles:

$$\sum_{d=1}^{D} qg_{bb,d,dd} \ge bb\_wg_{bb} \times bb\_fgddmin_{bb,dd} \qquad \vee\ bb=1,2,\ldots,BB \quad \vee\ dd=1,2,..,DD \quad (6)$$

$\mathrm{bb\_fgddmin}_{\mathrm{bb,dd}}$ is the minimum fraction of garbage from *bb* borough that is transported by *dd* type departmental vehicles.

Minimum amount of garbage dispatched from borough *bb* by hired vehicles *hh*:

$$\sum_{d=1}^{D} qhhg_{bb,d} \ge bb\_wg_{bb} \times bb\_fghhmin_{bb} \qquad \vee\ bb=1,2,\ldots,BB \quad (7)$$

$\mathrm{bb\_fghhmin}_{\mathrm{bb}}$ is the minimum fraction of garbage from *bb* borough that is transported by hired vehicles *hh*.

Equating feed to central sorter located at a disposal site *d*:

$$\sum_{bb=1}^{BB} \sum_{dd=1}^{DD} qg_{bb,d,dd} + \sum_{bb=1}^{BB} qhhg_{bb,d} = sgf_{d} \qquad \vee\ d=1,2,\ldots,D \qquad (8)$$

sgf_d is the feed to the central sorting station associated with disposal site *d*.

Balancing input and output streams for the central sorting facility located at disposal site *d*:

$$sgf_d = sr_d + sdd_d + sad_d + sif_d + scf_d \qquad \vee\ d=1,2,\ldots,D \qquad (9)$$

sr_d is the amount of recyclable material separated from the waste stream at the central sorting station associated with disposal site *d*, tons. sad_d is the additional amount of waste to be transferred directly from the sorting facility (after sorting but without any processing) to the landfill in case of emergency. sif_d is the feed from sorter to incinerator associated with disposal site *d*, tons. scf_d is the feed in tons entering the composting plant from sorter at a disposal site *d*. It is assumed that sdd_d, i.e. direct dumpable portion of solid waste (comprising of inert) is not sorted through sorter but is directly discharged to landfill after visual inspection.

Maximum amount recycled from sorter at disposal site *d*:

$$sr_d - sgf_d \times ics\_ry_d \leq 0 \qquad \vee\ d=1,2,\ldots,D \qquad (10)$$

ics_ry_d is the recyclable fraction of solid waste coming out from sorter at disposal site *d*.

Maximum amount sorted for direct dumpable at disposal site *d*:

$$sdd_d - sgf_d \times ics\_ddy_d \leq 0 \qquad \vee\ d=1,2,\ldots,D \qquad (11)$$

ics_ddy_d is the direct dumpable fraction of solid waste coming out from sorter at disposal site *d*.

Maximum amount of sorted feed to incinerator plant:

$$sif_d - sgf_d \times ics\_maxinci_d \leq 0 \qquad \vee\ d=1,2,\ldots,D \qquad (12)$$

$ics\_maxinci_d$ is the incinerable fraction of solid waste coming out from sorter at disposal site *d*.

Maximum amount of sorted feed to composting plant:

$$scf_d - sgf_d \times ics\_maxcomp_d \leq 0 \qquad \vee\ d=1,2,\ldots,D \qquad (13)$$

$ics\_maxcomp_d$ is the compostable fraction of solid waste coming out from sorter at disposal site *d*.

Balance of incinerator recyclables at disposal site *d*:

$$ir_d - sif_d \times ip\_ry_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (14)$$

ir_d is the recyclable portion sorted out from incinerator pre-sorter and dispatched to the recycling facility, tons. ip_ry_d is the recyclable fraction of waste coming out from incinerator at *d*. The incinerator pre-sorter is responsible for enhanced sorting and segregating out the recyclable fraction further.

Balance of incinerator inorganic rejects at disposal site *d*:

$$iir_d - sif_d \times ip\_iry_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (15)$$

iir_d is the inorganic reject portion separated from the incinerator pre-sorter and sent directly to landfill at a transportation cost of ip_irc_d per ton. ip_iry_d is the incineration inorganic reject fraction coming out from the incinerator, at disposal site *d*.

Balance of incinerator process ash rejects at disposal site *d*:

$$iar_d - sif_d \times ip\_ay_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (16)$$

iar_d is the incinerator ash being transported from the incinerator to the landfill site at a transportation cost of ip_ac_d per ton for a particular disposal site *d*. ip_ay_d is the incineration ash reject (incineration product) fraction generated from the incinerator feed, sif_d, at disposal site *d*.

Electricity / power generated from incinerator at disposal site *d*:

$$ip_d - sif_d \times f_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (17)$$

ip_d is the total kWh units of electricity generated by incinerator at disposal site *d*. f_d is the kWh units of electricity generated by processing unit in MT of MSW in incinerator at disposal site *d*.

Balance of composting plant recyclables at disposal site *d*:

$$cr_d - scf_d \times cp\_ry_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (18)$$

cr_d is the amount of waste recycled from the composting plant pre-sorter to the recycling facility, tons. cp_ry_d is the recyclable fraction of waste coming out from composting plant pre-sorter at *d*. The composting plant pre-sorter is responsible for segregating out this portion.

Balance of composting inorganic rejects at disposal site *d*:

$$cir_d - scf_d \times cp\_iry_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (19)$$

cir_d is the inorganic reject amount dispatched from composting pre-sorter to the landfill at a transportation cost of cp_irc_d per ton. cp_iry_d is the composting inorganic reject fraction coming out from the composting plant at disposal site *d*. The inorganic reject portion of waste is sorted out by the composting plant pre-sorter and transported directly to landfill.

Balance of composting process rejects at disposal site *d*:

$$cpr_d - scf_d \times cp\_pry_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (20)$$

cpr_d is the composting process reject amount in tons for a disposal site *d*. The process rejects are transferred directly to the landfill at a cost of cp_prc_d per ton. cp_pry_d is the compost plant process rejects fraction coming out from the composting plant, at disposal site *d*.

Balance of composting plant product at disposal site *d*:

$$cpd_d - scf_d \times cp\_prdy_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (21)$$

cpd_d is the compost produced in the composting plant in the disposal site *d*, tons. cp_prdy_d is the composting product (compost) fraction generated from composting plant feed, scf_d.

Balancing landfill amount at disposal site *d*:

$$xf_d - xsilt_d - xfg_d - xfrj_d = 0 \qquad \vee\ d=1,2,\ldots,D \qquad (22)$$

xf_d is the amount of solid waste being disposed off in the landfill associated with disposal site *d*, MT. $xsilt_d$ and xfg_d are the total amounts of silt and garbage transported to the landfill at a disposal site *d*. $xfrj_d$ are the rejects from different processing methods like incineration and composting transferred to landfill at disposal site *d*.

Balance of silt in landfill at disposal site *d*:

$$xsilt_d - \sum_{bb=1}^{BB} qhhs_{bb,d} = 0 \qquad \vee\ d=1,2,\ldots,D\ (23)$$

Balance of direct dumpable and additional dumpable amount at landfill at disposal site *d*:

$$xfg_d - sdd_d - sad_d \qquad \forall d = 1,2,\ldots,D (24)$$

Balancing all process rejects to landfill at disposal site *d*:

$$xfrj_d - iir_d - cir_d - iar_d - cpr_d = 0 \qquad \forall d = 1,2,\ldots\ldots,D\ (25)$$

Maximum and minimum capacity limits of central sorter at disposal site *d*:

$$sgf_d \leq ics\_capmax_d \qquad \forall d = 1,2,\ldots\ldots,D\ (26)$$

$$sgf_d \geq ics\_capmin_d \qquad \forall d = 1,2,\ldots\ldots,D\ (27)$$

ics_capmin_d and ics_capmax_d are the minimum and maximum capacity of the central sorting facility at a disposal site *d*.

Maximum and minimum capacity limits of incinerator at disposal site *d*:

$$sif_d \leq ip\_capmax_d \qquad \forall d = 1,2,\ldots\ldots,D\ (28)$$

$$sif_d \geq ip\_capmin_d \qquad \forall d = 1,2,\ldots\ldots,D\ (29)$$

ip_capmin_d and ip_capmax_d are the minimum and maximum capacity of the incinerator at a disposal site *d*.

Constraints for capacity of composting plant at disposal site *d*:

$$scf_d \leq cp\_capmax_d \qquad \forall d = 1,2,\ldots\ldots,D\ (30)$$

$$scf_d \geq cp\_capmin_d \qquad \forall d = 1,2,\ldots\ldots,D\ (31)$$

cp_capmin_d and cp_capmax_d are the minimum and maximum capacity of the composting plant at a disposal site *d*.

Constraints for capacity of landfill at disposal site *d*:

$$xf_d \leq lfcapmax_d \qquad \forall d = 1,2,....,D \quad (32)$$

lfcapmax$_d$ is the maximum capacity of the landfill at disposal site *d*. Minimum capacity of the landfill has been not fixed.

The municipality area is divided into *z* number of zones for each disposal site *d*. The zone divisions are made based on their proximity to the disposal site *d*. The municipality has fixed maximum trip limits (zz_maxtrip$_{dd,d,z}$) and minimum trip limits (zz_mintrip$_{dd,d,z}$) for each zone *z* of a disposal site *d* for a *dd*-type departmental vehicle. The drivers and the helpers are paid incentives if they undertake trips beyond the minimum trip limits stipulated for a particular zone. Similarly, the hired vehicles *hh* are paid according to the zone *z* (of a disposal site *d*) from where they are transferring waste. Constraints based on the number of trips made by departmental/hired vehicles in a zone *z* of a disposal site *d*are given below.

Number of trips made by departmental vehicles in a zone *z* of a disposal site *d*:

$$at_{dd,d,z} \times dd\_cap - \sum_{bb=1}^{BB} qg_{bb,d,dd} = 0 \qquad (33)$$

$$\forall dd = 1,2,....,DD \quad \forall d = 1,2,....,D \quad \forall z = 1,2,....,Z$$

$at_{dd,d,z}$ is the actual number of trips made by *dd* type vehicle to a zone *z* of a disposal site *d*. dd_cap$_{dd}$ is the average waste carrying capacity of a *dd* type of vehicle. In calculating $\Sigma qg_{bb,d,dd}$, only those *bb* boroughs are considered which belong to the zone *z* of the disposal site *d*.

Actual number of trips made by hired vehicles *hh* in a zone *z* of a disposal site *d* for collection of garbage:

$$athhg_{d,z} \times hhg\_cap - \sum_{bb=1}^{BB} qhhg_{bb,d} = 0 \qquad \forall d = 1,2,....,D \quad \forall z = 1,2,....,Z \quad (34)$$

$athhg_{d,z}$ is the actual number of trips made by hired vehicles *hh* in a zone *z* of a disposal site *d* for collection of garbage. hhg_cap is the average garbage carrying capacity for a hired vehicle *hh*. In calculating $\Sigma qhhg_{bb,d}$, only those *bb* boroughs are considered which belong to the zone *z* of the disposal site *d*.

Actual number of trips made by hired vehicles *hh* in a zone *z* of a disposal site *d* for collection of silt:

$$athhs_{d,z} \times hhs\_cap - \sum_{bb=1}^{BB} qhhs_{bb,d} = 0 \qquad \forall d = 1,2,....,D \quad \forall z = 1,2,....,Z \quad (35)$$

$athhs_{d,z}$ is the actual number of trips made by hired vehicles *hh* in a zone *z* of a disposal site *d* for collection of silt. hhs_cap is the average silt carrying capacity for a hired vehicle *hh*. In calculating $\Sigma qhhs_{bb,d}$, only those *bb* boroughs are considered which belong to the zone *z* of the disposal site *d*.

Considering maximum trips of *dd* type departmental vehicle in zone *z* of *d*:

$$at_{dd,d,z} \leq dd\_na_{dd} \times zz\_maxtrip_{dd,d,z} \qquad (36)$$

$$\forall dd = 1,2,....,DD \quad \forall d = 1,2,....,D \quad \forall z = 1,2,....,Z$$

zz_maxtrip$_{dd,d,z}$ is the maximum number of trips that a *dd* type departmental vehicle isallowed to undertake in zone *z* of disposal site *d*.

Maximum possible trip limit by *dd* type vehicle in all disposal site *d*, all zone *z*:

$$\sum_{d=1}^{D} \sum_{z=1}^{Z} at_{dd,d,z} \leq dd\_na_{dd} \times maxzz\_maxtrip_{dd} \qquad \forall dd = 1,2,....,DD \qquad (37)$$

For a particular *dd* type vehicle, considering all disposal sites *d*, the maximum value of zz_maxtrip$_{dd,d,z}$ is taken as maxzz_maxtrip$_{dd}$. dd_na$_{dd}$ is the number of *dd* type vehicles running.

Minimum possible trip limit by *dd* type vehicle in all disposal site *d*, all zone *z*:

$$\sum_{d=1}^{D} \sum_{z=1}^{Z} at_{dd,d,z} \geq dd\_na_{dd} \times minzz\_mintrip_{dd} \qquad \forall dd = 1,2,....,DD \qquad (38)$$

zz_mintrip$_{dd,d,z}$ is the minimum number of trips that a *dd* type departmental vehicle has to undertake in zone *z* of disposal site *d*. For a particular *dd* type vehicle, considering all disposal sites *d*, the minimum value of zz_mintrip$_{dd,d,z}$ is taken as minzz_mintrip$_{dd}$.

Balancing amount of garbage transported by *dd* type departmental vehicle to disposal site *d* from zone *z* of *d*:

$$dg_{dd,d,z} - \sum_{bb=1}^{BB} qg_{bb,d,dd} = 0 \qquad (39)$$

$$\forall dd = 1,2,....,DD \quad \forall d = 1,2,....,D \quad \forall z = 1,2,....,Z$$

$dg_{dd,d,z}$ denotes the amount of garbage transported by *dd* type departmental vehicle to a disposal site *d* from zone *z* of *d*. $\Sigma qg_{bb,d,dd}$ is the total amount of garbage taken by *dd* type vehicle to disposal site *d* from all those *bb* boroughs which belong to zone *z* of *d*.

Balancing amount of garbage transported by hired vehicle *hh* to disposal site *d* from zone *z*of *d*:

$$dghh_{d,z} - \sum_{bb=1}^{BB} qhhg_{bb,d} = 0 \qquad \forall d = 1,2,....,D \quad \forall z = 1,2,....,Z (40)$$

$dghh_{d,z}$ is the amount of garbage transported by hired vehicle hh to disposal site d from zone z of d. $\Sigma qhhg_{bb,d}$ is the total amount of garbage taken by hired vehicle hh to disposal site d from all those bb boroughs which belong to zone z of d.

Balancing amount of silt transported by hired vehicle hh to disposal site d from zone z of d:

$$dshh_{d,z} - \sum_{bb=1}^{BB} qhhs_{bb,d} = 0 \qquad \forall d = 1,2,\ldots,D \ \forall z = 1,2,\ldots,Z \quad (41)$$

$dshh_{d,z}$ is the amount of silt transported by hired vehicle hh to disposal site d from zone z of d. $\Sigma qhhs_{bb,d}$ is the total amount of silt taken by hired vehicle hh to disposal site d from all those bb boroughs which belong to zone z of d.

Total cost of sorting:

$$CTCS - \sum_{d=1}^{D}[sgf_d \times ics\_sortcost_d] - \sum_{d=1}^{D}[sr_d \times ics\_rc_d + sad_d \times ics\_adc_d] = 0 \quad (42)$$

ics_sortcost$_d$ is the sorting cost per ton of solid waste for the central sorting station associated with the disposal site d. ics_rc$_d$ is the cost of transporting recyclable material from the sorter associated with disposal site d to recycling facility, Rs/MT. Per ton cost of additional dumping is ics_adc$_d$, Rs/MT.

Total cost of incineration:

$$CTCI - \sum_{d=1}^{D}[sif_d \times ip\_opcost_d + ir_d \times ip\_rc_d + iar_d \times ip\_ac_d + iir_d \times ip\_irc_d] = 0 \quad (43)$$

ip_opcost$_d$ is the operational cost of the incinerator at disposal site d, Rs/MT. It includes the construction and operational cost of incinerator and the transportation cost from the sorting facility to the incinerator. ip_rc$_d$ is the per ton transportation cost of the recyclables from the incinerator pre-sorter attached to the disposal site d to the recycling facility. Incinerator ash products, iar_d, are transported from the incinerator to the landfill site at a transportation cost of ip_ac$_d$ per ton for a particular disposal site d. Inorganic reject portion, iir_d, separated from the incinerator pre-sorter are sent to landfill associated with a particular disposal site d at a transportation cost of ip_irc$_d$ per ton.

Total cost of composting:

$$CTCC - \sum_{d=1}^{D}[scf_d \times cp\_opcost_d + cr_d \times cp\_rc_d + cir_d \times cp\_irc_d + cpr_d \times cp\_prc_d] = 0 \quad (44)$$

cp_opcost$_d$ is the operational cost of the composting plant including cost of construction and operation of composting plant and transportation cost from the central sorting facility to composting plant, Rs/MT. cp_rc$_d$ is the per ton transportation cost of recyclables from composting pre-sorter for a particular disposal site d to recycling facility. cir_d is the inorganic reject amount dispatched from composting pre-sorter to the landfill at a transportation cost of

cp_irc_d per ton. The composting process rejects for a disposal site *d*, cpr_d, are transferred directly to the landfill at a cost of cp_prc_d per ton.

Total cost of landfilling:

$$CTCX - \sum_{d=1}^{D} lfc_d \times xf_d = 0 \tag{45}$$

lfc_d is the landfilling cost in Rs/MT for the landfilling site associated with the disposal site *d*. It includes the cost of land, cost of liner, leachate management, final cover, etc.

Total revenue generated by selling recyclable materials:

$$CTREVR - \sum_{d=1}^{D} [sr_d \times ics\_rr_d + ir_d \times ip\_rr_d + cr_d \times cp\_rr_d] = 0 \tag{46}$$

ics_rr_d is the revenue earned from selling per ton of recyclable materials generated from the sorting station attached to disposal site *d*. ip_rr_d and cp_rr_d are the revenues earned from selling recyclable materials sorted out from incinerator pre-sorter and composting pre-sorter respectively, Rs/MT.

Total revenue generated by selling compost:

$$CTREVC - \sum_{d=1}^{D} [cpd_d \times cp\_prdc_d] = 0 \tag{47}$$

cp_prdc_d is the selling price of the compost per ton.

Total revenue generated by selling electricity from incinerator:

$$CTREVI - \sum_{d=1}^{D} [ip_d \times ip\_rev_d] = 0 \tag{48}$$

ip_rev_d is the revenue earned in selling one kWh unit of electricity generated from the incinerator associated with disposal site *d*, Rs/kWh.

Total cost of transportation of waste to all the disposal sites:

$$CTRANSP - ctchh - \sum_{d=1}^{D} ctcdd_d = 0 \tag{49}$$

Total cost of transportation of solid waste to the disposal sites includes the transportation cost for hired vehicles *hh* as well as the cost of transportation incurred by the departmental vehicles *dd*. *ctchh* denotes the total cost of transportation of waste by hired vehicles. $ctcdd_d$ denotes waste transportation cost by *dd* type departmental vehicles. Incidentally, hired vehicles collect and transport both garbage and silt, while departmental vehicles transport garbage only. There is only one type of hired vehicle. Haulage capacities of garbage and silt/rubbish for hired vehicle are considered different. Rates for garbage and silt collections are different. Also, garbage and silt transportation charges by hired vehicles are paid to them on the basis of different zones from which the wastes are being transported. All liabilities of hired vehicles are the responsibility of the respective private agencies.

Total cost of waste transportation by hired vehicles from borough centres to disposal sites:

$$ctchh - ctcghh - ctcshh = 0 \qquad (50)$$

Total cost of transportation by hired vehicles is the summation of garbage transportation cost by hired vehicles from borough centers to disposal sites, *ctcghh*, and the silt transportation cost by hired vehicles from borough centers to disposal sites, *ctcshh*.

Total cost of garbage transportation by hired vehicles from borough centres to disposal sites:

$$ctchh - \sum_{bb=1}^{BB} \sum_{d=1}^{D} [qhhg_{bb,d} \times bb\_hcg_{bb,d}] = 0 \qquad (51)$$

$bb\_hcg_{bb,d}$ is the per ton transportation cost of garbage from borough *bb* center to disposal site *d* for a hired vehicle, Rs./MT.

Total cost of silt transportation by hired vehicles from borough centres to disposal sites:

$$ctcshh - \sum_{bb=1}^{BB} \sum_{d=1}^{D} [qhhs_{bb,d} \times bb\_hcs_{bb,d}] = 0 \qquad (52)$$

$bb\_hcs_{bb,d}$ is the per ton transportation cost of silt from borough *bb* center to disposal site *d* for a hired vehicle, Rs./MT.

Total cost of garbage transportation by *dd* type departmental vehicles is the summation of fuel cost, fixed cost of running vehicles and fixed cost of idle vehicles.

Waste transportation cost by *dd* type departmental vehicle from borough centre to disposal sites:

$$ctcdd - cfueldd - cfxdrdd - cfxdidd = 0 \qquad \forall dd = 1,2,.....,DD \ (53)$$

cfueldddd is the cost of fuel incurred by *dd* type departmental vehicles for waste transportation. $cfxdrdd_{dd}$ and $cfxdidd_{dd}$ are the total fixed cost for running and the total fixed cost for idle *dd* type departmental vehicles. The fixed costs include annualised capital cost of vehicles, maintenance cost and driver/helper cost. Everyday approximately 50 to 80% of the departmental vehicles run; other remain in idle/standby condition.

The cost of fuel incurred by *dd* type departmental vehicle:

$$cfueldd_{dd} - \sum_{bb=1}^{BB} \sum_{d=1}^{D} [qg_{bb,d,dd} \times bb\_fc_{bb,d,dd}] = 0 \qquad \forall dd = 1,2,.....,DD (54)$$

$bb\_fc_{bb,d,dd}$ is the average fuel cost for transporting per ton waste from borough *bb* to disposal site *d* by a *dd* type vehicle.

Total fixed cost for running *dd* type departmental vehicle:

$$cfxdrdd_{dd} - dd\_na_{dd} \times dd\_fc_{dd} = 0 \qquad \forall dd = 1,2,.....,DD \quad (55)$$

dd_fc_{dd} is the fixed cost for running each *dd* type vehicle.

Total fixed cost for idle *dd* type departmental vehicle:

$$cfxdidd_{dd} - (dd\_no_{dd} - dd\_na_{dd}) \times dd\_ic_{dd} = 0 \qquad \forall dd = 1,2,.....,DD \quad (56)$$

dd_no_{dd} is the total number of *dd* type of departmental vehicles in the municipality's fleet. dd_ic_{dd} is the fixed idle cost for each *dd* type vehicle.

Calculation of incentives to be paid to *dd*-type departmental vehicle drivers and helpers can be approximated by:

$$CINCENT - \sum_{dd=1}^{DD} cinc_{dd} = 0 \qquad (57)$$

$$cinc_{dd} = \left[\sum_{z=1}^{Z} \sum_{d=1}^{D} dg_{dd,d,z} \times r_{incdd}\right] - dd\_na_{dd} \times minzz\_mintrip_{dd} \times dd\_cap_{dd} \times r_{incdd}$$

$$\forall dd = 1,2,.....,DD \quad (58)$$

$cinc_{dd}$ is the amount of incentive (in Rs.) to be paid to a *dd*-type vehicle for transporting waste more than the minimum stipulated number of trips. r_{inc} is the rate of incentive (per extra ton basis) to be paid to the driver and helper of a *dd* type vehicle for transporting waste over and above the minimum trips.

5.2 METHODOLOGY:

To generate and solve the LP equations, a software programme was developed in LINGO v 9.0 (LINDO Stystems Inc.) optimisation software. LINGO is a software tool for utilising the power of linear and nonlinear optimisation to formulate large problems concisely, solve them, and analyse the solution (LINDO Systems Inc., 2004) and can be run on Windows platform. The various input data for running the programme was fed into Excel spreadsheets. LINGO has the ability to interface with external databases like data stored in Excel spreadsheets. LINGO thus imported data from these spreadsheets, generated equations, solved the model and gave the results in the form of a solution report. After interpreting the solution report, relevant data tables were generated in Excel. A flow chart of the entire process is given below:

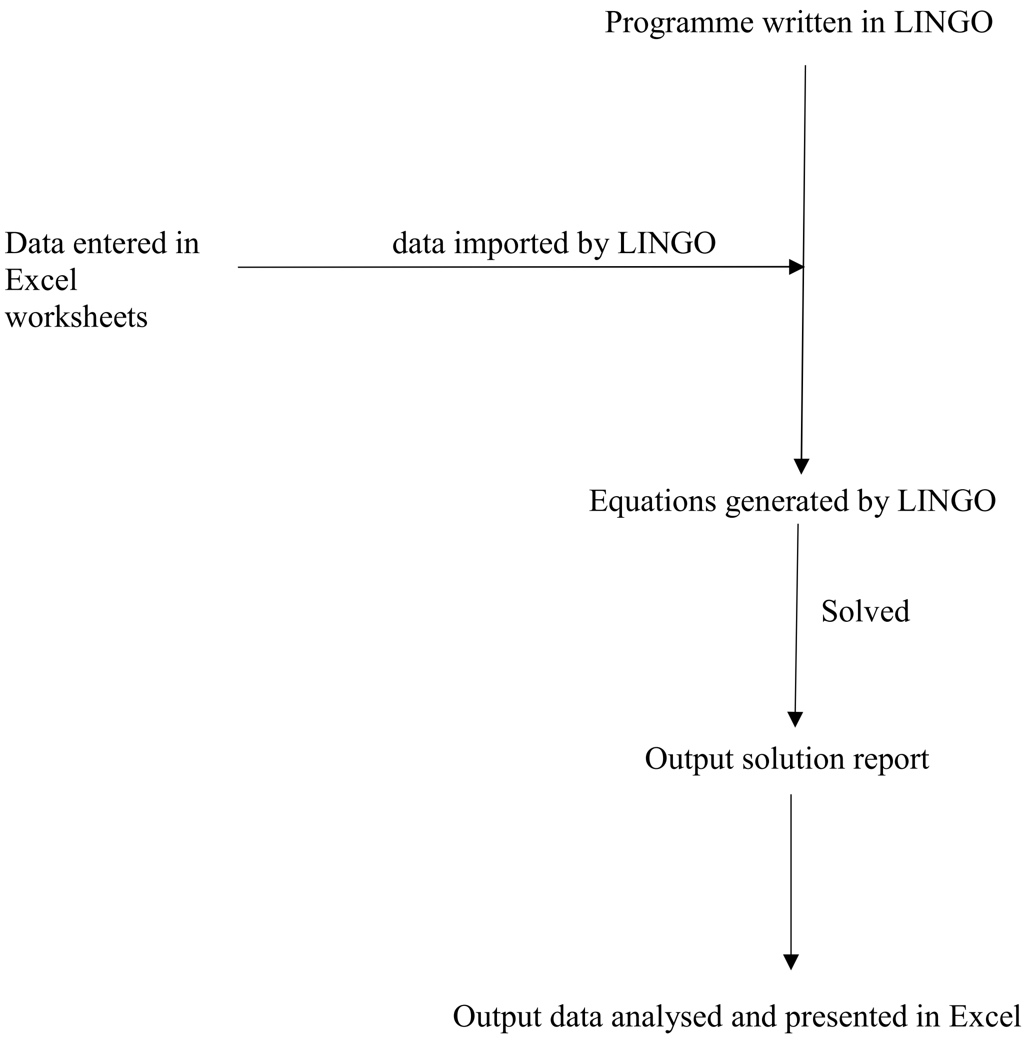

Figure 5.2 Flowchart detailing steps for running the model in LINGO

6. RESULT AND DISCUSSION

6.1 APPLYING THE MODEL FOR KMC AREA

Presently, there is no incinerator/RDF plant in Kolkata; neither waste segregation/sorting exist nor is sanitary/engineered landfilling practised. A 700 MT/d compost plant running on PPP (public-private partnership) model at Dhapa disposal ground processes only 150 MT/d during most of the times. However, with the Ministry of Urban Development, Govt. of India promoting and funding "Swachh Bharat Mission" in a big way, one expects SWM will be managed in a more modern and scientific way in very near future. The chapter thus proposes the above-mentioned LP model for simulating such an ISWM system for Kolkata — two-bin system at household level, sorting stations, processing plants and engineered landfills but with the same waste characteristics and waste transportation infrastructure as currently exist — with the ultimate goal to optimise the overall cost of such an SWM system.

The physical composition and characterisation of Kolkata MSW is presented in Table 6.1, Table 6.2 and Table 6.3; from these tables, composition of recyclable materials is computed as shown in Table 6.4. We have taken many data for our model from the research paper of Chattopadhyay et al. 2009, Paul et al. 2014 and Paul et al. 2015.

Table 6.1 Variation in MSW composition at Kolkata during 1970, 1995 and 2005 **(NEERI, 1995, 2005)**

SI. No.	Parameters	1970	1995	2005
1	Biodegradable	40.36	44.29	50.56
2	Green coconut shell	4.95	8.51	4.5
3	Paper	3.17	4.64	6.07
4	Plastics	0.64	3.22	4.88
5	Metals	0.66	0.43	0.19
6	Glass & Crockery	0.38	1.72	0.34
7	Coal	6.08	3.10	-
8	Inert	40.76	26.82	29.6
9	Others*	3.00	7.27	3.86

*All values are in percent by net weight   * Bio-resistant and synthetic material*

Table 6.2 Variations of MSW composition (Chemical Parameters) at Kolkata during 1970, 1995 & 2005 **(NEERI, 1995, 2005)**

SI. No.	Parameters	1970	1995	2005
1	Moisture	42.84%	61.57%	46%
2	pH	7.31	6.33	0.3-8.07
3	Loss of Ignition	35.24%	46.78%	38.53%
4	Carbon	19.58%	25.98%	22.35%
5	Nitrogen as N	0.55%	0.88%	0.76%
6	Phosphorous as P_2O_5	0.57%	0.58%	0.77%

7	Potassium as K_2O	0.40%	0.93%	0.52%
8	C/N Ratio	35.60	29.53	31.81
9	LCV Kcal/Kg	549.32	648.91	1201

All values are in percent by dry weight basis except pH & LCV

Table 6.3 Average physical composition of municipal solid waste in KMC area **(Chattopadhyay et al. 2007)**

Total compostable	**Recyclables**				**Other including Inerts**						**Total**
	Paper	**Plastic**	**Glass**	**Metal**	**Inert**	**Rubber and Leather**	**Rags**	**Wooden matter**	**Coconut**	**Bone**	
50.56	6.07	4.88	0.34	0.19	29.6	0.68	1.87	1.15	4.50	0.16	100.0
50.56	11.48				37.96						100.0

Table 6.4 Proportion of recyclable materials in Kolkata at present **(Chattopadhyay et al. 2007)**

Materials	**Original Composition**	**Recyclable portion at source and at landfill site**
Paper	6.07	5.00 (82%)
Plastic	4.88	3.38 (70%)
Glass	0.34	0.27 (80%)
Metal	0.19	0.15 (80%)
From others :		
Rubber & leather	0.68	0.41 (60%)
Total	12.16	9.21[*]

*Out of this 9.21%, about 5% is recycled at household level and 4.21% is recycled by rag pickers in the existing system

From data presented in Table 6.3 and Table 6.4, the amount of total recyclable materials (Table 6.5), total input material composition for the incinerator (Table 6.7) and total input for composting plant (Table 6.6) located at each of the proposed disposal sites have been calculated, considering a total garbage generation of 100 MT.

Table 6.5 Total recyclable waste components in garbage

Waste components	**Quantity (T)**
Paper	5
Rubber & Leather	0.34
Plastic	4.88
Glass	0.34
Metal	0.19
Total Recyclable	**10.75**

Table 6.6 Composition of composting plant feed

Composting					
Compostable	**Recyclable**	**Inert**			**Total**
(50.56−3[*]) = 47.56	1.25	3.0[#]	4.0[$]	9.19[&]	65

*3 tons of compostable material enters as incineration feed due to inefficiency of central sorter
#3 tons of inert present in composting product i.e. compost
$4 tons of inert rejects at composting pre-sorter
&9.19 tons of inert rejects during composting process

Table 6.7 Input material composition for thermal processing

Waste components	**Quantity (T)**
Paper	1.07
Rubber & Leather	0.34
Rags	1.87
Wooden Matter	1.15
Coconut shell	4.5
Bones	0.16
Inert in incineration feed (due to inefficiency of central sorter)	2.41
Compostable portion in incineration feed (due to inefficiency of central sorter)	3
Sorted out material during presort operation in thermal treatment unit	
Inert	1
Recyclable material	0.15
Total Combustible	**16**

Similar calculations for amount of recyclable materials sorted out from different processing techniques in a disposal site in shown in Table 6.8. Table 6.9 shows inert materials obtained from various operations.

Table 6.8 Amount of recyclable materials sorted out from different operations

Operations	**Recycled quantity (Tons)**
Improved sorting at source (house-hold level)	5
Intermediate central sorting	4
Pre-sorting in Thermal Processing	0.5
Pre-sorting in Composting	1.25
Total Recycled	**10.75**

Table 6.9 Segregation of inert materials from different operations

Operation	**Quantity (Tons)**
Rejects from intermediate sorting	10
Presorting from thermal processing	1
Presorting from composting / biological processing	4
In combustion	2.41
Residue from composting / biological processing	9.19
In composted material	3
Total	29.6

With the help of Tables 6.3 to Table 6.9, Figure 5.1 can be modified to Figure 6.1 for simulating Kolkata MSW system.

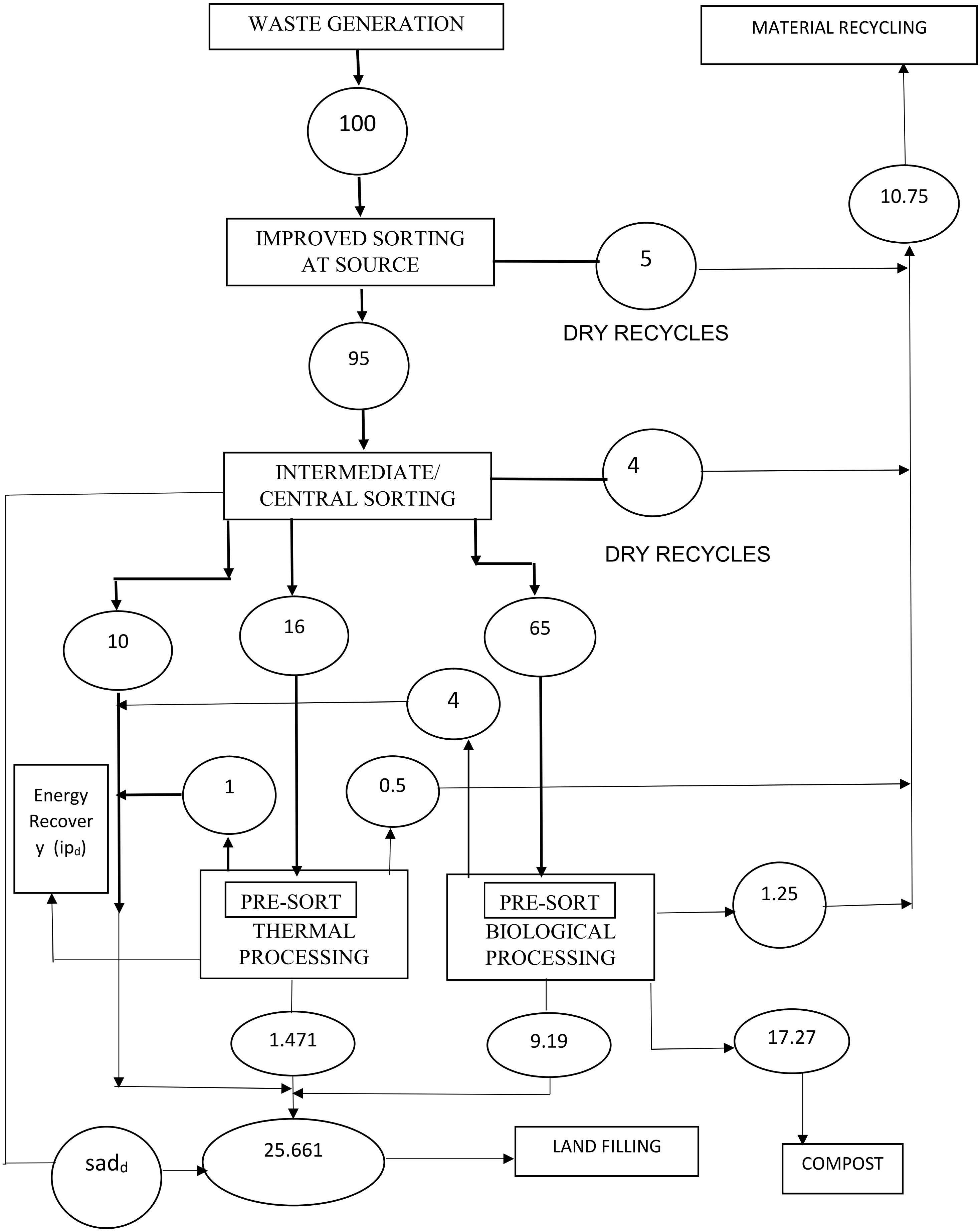

Figure 6.1 Materials flow chart for garbage at a disposal site **(Chattopadhyay et al. 2007)**

6.1.1 Disposal sites

Considering the fact that landfill space for Dhapa has already got exhausted, the KMC based model assumes three disposal sites at North (near Akandaberia, Haroa), South (near Kalicharanpur village, Nepalgunj) and East (near Noara, Bodura) of Kolkata **(Paul et al. 2014)**. A borough may find it economic to divert its waste to any of the North, South or East disposal sites as dictated by the model results. Each disposal site has a central sorting station, an incinerator, a composting plant and an engineered landfill facility. The shortest path distance between each borough center (assumed to be waste source) and disposal site has been taken from the research paper of Kaushik Paul **(Paul et al. 2015)** where he calculated the shortest distance using Network Analyst of ArcGIS. Each disposal site is associated with zones. In this case, each of the three disposal sites has two zones. Zone 1 consists of boroughs near to that disposal site, while Zone 2 comprises of boroughs far away from that disposal site. The borough-zone divisions and the distances of the borough centres to the disposal sites are shown in Table 6.10, Table 6.11, Table 6.12 **(Paul et al. 2014)**.

Table 6.10 Borough wise distance and their zones (E disposal site)

Zone 1	**Disposal from E disposal site (Km)**	**Zone 2**	**Disposal from E disposal site (Km)**
Borough 3	33.4	Borough 1	37.7
Borough 4	34.5	Borough 2	35.5
Borough 5	33.28	Borough 9	36.91
Borough 6	33.22	Borough 11	36.47
Borough 7	29.26	Borough 13	39.39
Borough 8	33.06	Borough 14	41.88
Borough 10	34.44	Borough 15	43.58
Borough 12	29.44		

Table 6.11 Borough wise distance and their zones (N disposal site)

Zone 1	**Disposal from N disposal site (Km)**	**Zone 2**	**Disposal from N disposal site (Km)**
Borough 1	32.6	Borough 8	40.7
Borough 2	33.1	Borough 9	43.08
Borough 3	32.3	Borough 10	44.3
Borough 4	34.6	Borough 11	47.09
Borough 5	35.9	Borough 12	42.22
Borough 6	36.8	Borough 13	47.53
Borough 7	38.07	Borough 14	48.62
		Borough 15	49.01

Table 6.12 Borough wise distance and their zones (S disposal site)

Zone 1	**Disposal from S disposal site (Km)**	**Zone 2**	**Disposal from S disposal site (Km)**
Borough 8	16.79	Borough 1	27.1
Borough 9	17.75	Borough 2	24.7
Borough 10	14.76	Borough 3	25.5
Borough 11	13.6	Borough 4	23.2
Borough 12	19.94	Borough 5	21..9
Borough 13	12.3	Borough 6	21.1
Borough 14	15.6	Borough 7	21.08
		Borough 15	25.03

6.1.2 Sorting and recycling

In the integrated solid waste management system three disposal sites sites are considered— one each in eastern side, northern side and southern side of Kolkata. In each site, central sorting system, composting and incineration facilities are considered. In ISWM system two bin system — one for bio-degradable waste and other for non-bio-degradable waste is considered at household level. Non-biodegradable recyclable portions sorted at household level are ~ 5% of the total waste generation. Revenue from this 5% of recyclable portion has not considered in this model since this is sold at the household level without KMC getting any revenue. Rest 95% garbage, which is recorded by KMC reaches to the Intermediate /Central Sorting facility (ICS).

After visual inspection at the ICS, 10% of waste (inert material) goes directly to the landfill site without unloading at ICS as direct dumpable inert portion from the garbage. Input/output stream at ICS is shown in Figure 6.2. Since 95% of the garbage reaches the ICS, to find out the percentages of the output streams from ICS, the mass values in Figure 6.1 are divided by 0.95.

Transportation of incineration feed and compost feed from ICS to incineration and compost plant is considered within the operating cost of these two units. Cost of transportation from processing plants (sorter, incineration, composting) to landfill site is assumed as Rs.15/MT/km. It is further assumed that sorter, incinerator, composting plant are within 2 km of each other.

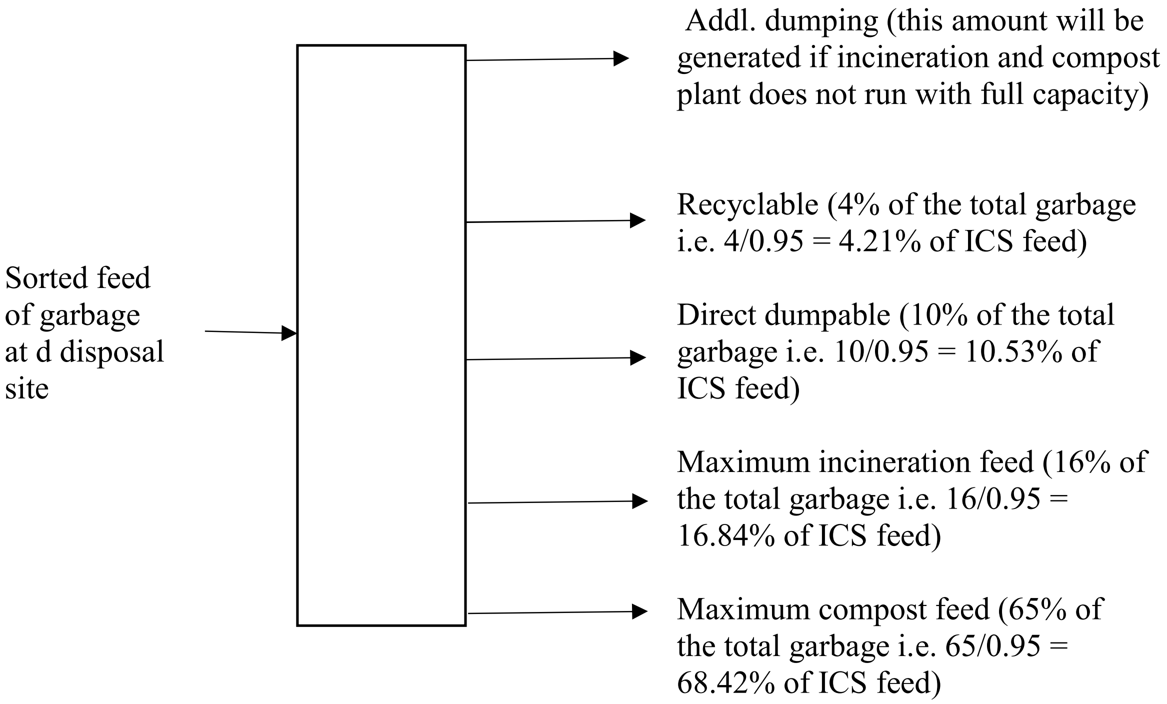

Figure 6.2 ICS balance

6.1.3 Balance for incinerator

Three WTE incineration plants are considered at three disposal sites along with other facilities. Maximum incineration feed is 16.84% of respective ICS feed of that site only. Composition of incineration feed is shown in Table 6.7. Input and output streams of the incineration plans are given in Figure 6.3.

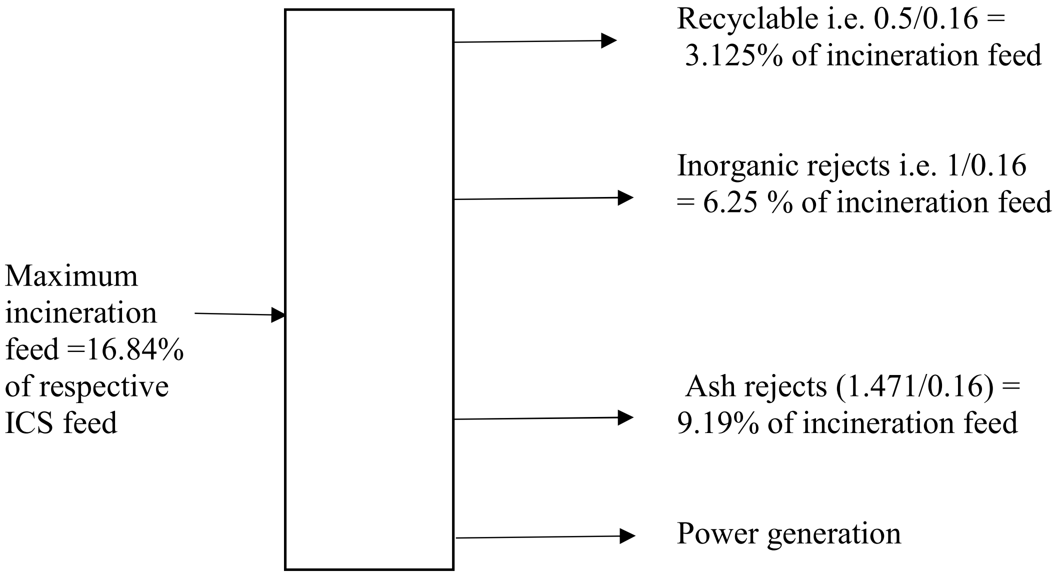

Figure 6.3 Balance for incinerator

6.1.4 Balance for composting

Three compost plants are considered in the three disposal sites along with other facilities. Mechanised windrow composting is considered and the composition of composting feed is given in Table 6.6. Mechanised windrow method is practised in many municipalities in India, since it is cheaper than both static pile method and anaerobic method. Also, the anaerobic method requires skilled supervision. Maximum compost feed is 68.42% of the respective ICS feed of that disposal site only. Input and output streams of compost plants are given in Figure 6.4.

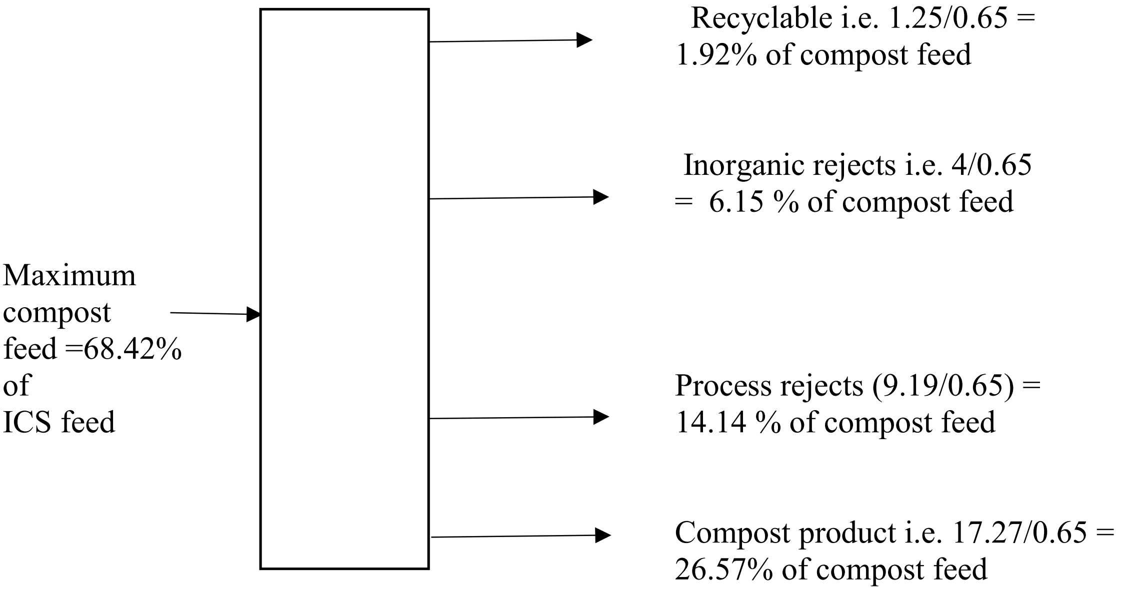

Figure 6.4 Balance for composting

6.1.5 Revenue from recyclable materials

To calculate the revenue for recyclable materials, recycling rate of paper, rubber &leather, plastic, glass, metal has been assumed as Rs.9/kg, Rs. 0.3/kg, Rs. 9/kg and Rs.1/kg and Rs. 50/kg respectively.

6.1.6 Revenue from compost

According to a validation report prepared by *Det Norske Veritus* titled '"Expansion of Nature and Waste Bhalaswa Composting Plant at Delhi" in India', revenue from compost sale varied between Rs 1741/MT to Rs. 2700/MT during the period 2006–2009 in Delhi. In this work, revenue from compost is assumed as Rs. 2500/MT

6.1.7 Operational and maintenance cost of composting plant

Cost of composting is taken as Rs. 269/MT **(Paul K. et al. 2017)**.

6.1.8 Operational and maintenance cost of incineration plant

O & M cost of mass-burn WTE incineration plant is Rs. 689/MT and that for RDF based WTE incineration plant is Rs. 1435/MT **(Paul K. et al. 2017)**.

6.1.9 Operational and maintenance cost of engineered landfill

As because we have taken our landfill site for this model from the research paper of Kaushik Paul. So we have also taken the cost of landfill from that research paper. The cost of landfill are 197.5 Rs/MT for **East** (*at Noara,Bodura*), 204.14 Rs/MT for **North** (*at Akandaberia village, Haroa/Basirhat)* , 193.58 Rs/MT for **South** (*at Kalicharanpur village, Nepalgunj*) **(Paul K. et al. 2014)**.

6.1.10 Borough-wise garbage and silt/rubbish generation

Average daily garbage and silt/rubbish generation in each of 15 boroughs in KMC area at present is given in Table 6.13 **(Paul K. et al. 2017)**. KMC records 95% of total waste generated while 5% is recycled at the house-hold level.

Table 6.13 Borough wise average daily garbage and silt / rubbish generation

Br. No.	Total Garbage(TPD)			Total Silt+ Rubbish (TPD)			Total Waste (TPD)
	Max.	Min.	Avg.*	Max.	Min.	Avg.*	Avg.*
01	212.8	194.62	196.28	32.33	12.31	21.11	214.43
02	206.8	184.39	192.63	32.82	3.16	12.63	202.12
03	223.58	180.38	197.43	33.05	9.87	21.09	215.53
04	225.28	148.46	171.85	25.72	7.66	13.35	182.46
05	229.65	204.44	207.33	29.04	9.13	18.0	222.07
06	258.26	225.11	257.64	64.75	15.94	36.9	290.91
07	304.42	227.38	265.67	92.61	46.26	65.7	328.39
08	189.93	162.53	176.43	76.38	19.99	42.08	216.51
09	319.78	265.07	292.6	45.36	13.29	27.2	315.27
10	426.51	309.30	370.61	80.16	11.32	32.5	397.26
11	111.35	99.98	105.0	3.64	0.71	1.89	105.04
12	99.8	85.40	91.89	6.69	0.21	2.36	92.65
13	197.47	161.27	172.75	14.64	0.954	4.14	173.86
14	164.11	122.99	142.19	20.33	4.34	9.84	149.73
15	27.52	23.89	24.4	0.44	0.292	0.06	24.02

* Average values were considered only

6.1.11 Types of vehicles currently used by KMC for transportation

At present, waste transport system utilises private-owned lorries to transport 40% of the daily generated garbage and entire amount of the silt/rubbish. Haulage capacity of these privately-owned vehicles is 7 MT for garbage and 9 MT for silt, assuming waste is being loaded onto these lorries using payloaders. Each lorry visits open vat location(s) and after their haulage capacity is exceeded, the vehicles proceed to the dumping ground.

The remaining 60% of MSW (garbage only) is transported by six categories of KMC owned vehicles. Of late, KMC has embarked on modernising its waste transportation fleet by purchasing compactors and the transportation system has undergone remarkable change over the last few years. The six types of departmental vehicles KMC is currently using are:

- Container carrying vehicles (Dumper-Placers): One Dumper-Placer (DP) can hoist and transport only one skip/container at a time to the disposal ground. KMC currently uses two types on skips — 4.5 m3 size (1.75 MT haulage capacity DP) and7 m3 size (2 MT haulage capacity DP). **DD1** and **DD2** refer to 1.75MT and 2MTDumper Placer respectively.

- Payloader loaded Tipper Trucks (11m3/7MT), **DD3**: These trucks haul around 7.0MT of MSW in one single trip to disposal site.

- Stationary compactor-cum-hook loader combination (10.5m3/9MT). **DD4**: KMC is purchasing 198 stationary compactors to be placed at 85 compactor stations. These compactors reduce 30% waste volume by applying 140 bar pressure. KMC is also acquiring 54 hook loaders, to haul these stationary compactors to the disposal site. Each hook loader can haul one stationary compactor at a time.

- Movable compactors (14m3/10MT). **DD5**: KMC is purchasing 64 numbers of 14m3capacity movable compactors. It takes waste from six 4.5m3 skips (or from handcarts), compact it at 140 bar pressure, and hauls waste to the landfill site.

- Movable compactors (8m3/7MT). **DD6**: KMC is purchasing 4 numbers of 8m3capacity movable compactors. These smaller sized compactors can manoeuvre narrow streets and lanes.

6.1.12 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Borough wise garbage disposal is analysed considering maximum and minimum fraction of waste carried by departmental type vehicles DD1, DD2, DD3, DD4, DD5, DD6 and hired vehicle HH type. From existing data it reveals that garbage carrying capacity of different vehicles varies by ± 5%. Due to above reason and allowing flexibility, maximum and minimum limit of garbage carrying capacity by both departmental and hired vehicles are varied by around same percentage, Table 6.14 **(Paul K. et al. 2017).**

Table 6.14 Borough-wise minimum & maximum garbage carrying quantity range (in fraction) for departmental and hired vehicles

Br.	DD1		DD2		DD3		DD4		DD5		DD6		HH	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	0	0.01	0.04	0.14	0.03	0.13	0.22	0.32	0.36	0.46	0	0	0.1	0.2
2	0	0	0.04	0.14	0	0.07	0.23	0.33	0.38	0.48	0	0	0.1	0.2
3	0	0.04	0.09	0.19	0	0.1	0.21	0.31	0.35	0.45	0	0	0.08	0.18
4	0	0	0.02	0.12	0.02	0.12	0.23	0.33	0.37	0.47	0	0	0.1	0.2
5	0	0	0	0.01	0.04	0.14	0.25	0.35	0.39	0.49	0	0	0.1	0.2
6	0	0	0	0.01	0	0.1	0.27	0.37	0.43	0.53	0	0	0.08	0.18
7	0	0	0.02	0.12	0	0.07	0.25	0.35	0.4	0.5	0	0	0.09	0.19
8	0	0	0.04	0.14	0	0.1	0.24	0.34	0.39	0.49	0	0	0.07	0.17
9	0	0	0.03	0.13	0	0.09	0.24	0.34	0.38	0.48	0	0	0.1	0.2
10	0	0	0.03	0.13	0	0	0.26	0.36	0.41	0.51	0	0	0.1	0.2
11	0.13	0.23	0	0	0	0.09	0.12	0.22	0	0.05	0.08	0.18	0.39	0.49
12	0.12	0.22	0	0	0	0.1	0.11	0.21	0.38	0.48	0.05	0.15	0.02	0.12
13	0.08	0.18	0	0	0.02	0.12	0.08	0.18	0.13	0.23	0.03	0.13	0.24	0.34
14	0.04	0.14	0	0	0.02	0.12	0.09	0.19	0.25	0.35	0.05	0.15	0.24	0.34
15	0	0	0	0	0	0.01	0	0	0	0	0	0	0.94	1

6.1.13 Maximum and minimum trip limits for departmental vehicles

For departmental vehicles, maximum and minimum trip limits are considered. Maximum and minimum trip limits of departmental vehicles are predicted based on past few years of KMC data on availability of vehicles in different garages, use of vehicles in different boroughs, the number of trips by different vehicles, amount of waste transportation. Each running departmental vehicles has to make minimum trips. Incentives are given to the drivers and helpers for carrying wastes more than the minimum trip but up to the maximum trip limit. Maximum and minimum trip limits and incentive of departmental vehicles for each zone associated with the three disposal sites has been predicted in Table 6.15 based on the existing scenario for Dhapa.

Table 6.15 Maximum and minimum trip limits of departmental vehicles and their incentive (for E, N & S transfer stations)

Type of departmental vehicles	Zone 1 (near transfer station)		Zone 2 (far from transfer station)		Capacity (MT)	Incentive rate per extra ton (Rs / MT)
	Max. trip	Min. trip	Max. trip	Min. trip		
DD1(1 driver and 1 helper)	6	3	6	2	1.75	30
DD2(1 driver and 1 helper)	8	3	6	2	2	21
DD3(1 driver and 1 helper)	8	3	4	2	7	15
DD4(1 driver and 1 helper)	6	3	4	2	9	22
DD5(1 driver and 1 helper)	4	2	3	2	10	17
DD6(1 driver and 1 helper)	4	2	3	1	7	17

Note: Total incentive rate (Rs / MT) = (Incentive rate of Driver, Rs / MT) + (Incentive rate of Helper, Rs / MT) × No. of Helper

6.1.14 Transportation cost

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the treatment and disposal site. Transportation cost of departmental vehicles is the summation of fuel cost, fixed running cost and fixed idle cost. KMC is responsible for procurement, operation and maintenance of its departmental vehicles. Fuel is issued from different departmental garages to the departmental vehicles and fuel consumption for four different types of departmental vehicles is considered on the basis of loaded run condition and empty run condition. Fixed running cost of departmental vehicles is calculated on the basis of depreciation, interest, and all wages for different types of running vehicles. Similarly for idle vehicles i.e. vehicles under maintenance, the fixed costs of different departmental vehicles are estimated on the basis of depreciation, interest, and maintenance wages only. Garbage and silt transportation costs (Rs /MT) by hired vehicles are paid on the basis of different zones. All other costs like capital, depreciation, fuel, maintenance and wages are included in the mutually approved zone wise rates for garbage and silt. All liabilities of hired vehicles are the responsibility of the respective private agencies.

Transportation cost calculated separately for different case study.

For running the model we have taken data from researcher Paul et al. (2017), and we have run our combination with the data set of transfer station near KMC boundary. We have also taken many data which require for running the model from researcher Paul et al. (2017) and Chattopadhyay et al. (2018).

6.2 VALIDATING THE MODEL WITH 2007 KMC SWM DATASETS

To validate the model with KMC solid waste management datasets, certain changes are required to be made in the data assumed in sub-chapter 6.1. Thus, sub-chapter 6.2 includes actual data from KMC records for the year 2007. Some data also taken from researcher **(Chattopadhyay et al. 2009)**.

6.2.1 General Description and Disposal sites

In the existing MSW management system open dumping of waste without any liner and gas collection system is practiced. Borough wise (borough I to borough XV) 15 regions are selected and only one landfill site at the eastern fringe of Kolkata, Dhapa is considered along with composting facility. As the existing dumping ground, Dhapa is about 10 KM distance from the center of the city so at present department (KMC) does not have any transfer station.

6.2.2 Types of KMC departmental vehicles

Till 2009-2010, the departmental vehicles were of the four following types:

- Container carrying vehicles (Dumper-Placers): One Dumper-Placer (DP) can hoist and transport only one skip/container at a time to the disposal ground. KMC currently uses two types on skips — 4.5 m3 size (1.75 MT haulage capacity DP) and 7 m3 size (2 MT haulage capacity DP). **DD1** and **DD2** refers to 1.75 MT skip and 2 MT skip respectively.

- Manually loaded Tipper Trucks (**DD3**), 8m3: They haul around 3 MT of MSW to the Dhapa landfill site from various open vats/open dumping areas in one trip.

- Payloader loaded Tipper Trucks (**DD4**), 11m3: They haul around 7 MT of MSW in one single trip to Dhapa. These vehicles collect MSW from various open vats and after collecting around 7 MT of wastes, it proceeds to Dhapa.

6.2.3 Borough Wise Garbage and Silt or Rubbish Generation

Average daily garbage and silt/rubbish generation in each of the 15 boroughs for the year 2007 is given in Annexure 6.1.

6.2.4 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Borough wise garbage disposal in 2007 is analysed considering maximum and minimum fraction of waste carried by departmental type vehicles DD1, DD2, DD3, DD4 and hired vehicle HH type. Accordingly maximum and minimum limit of garbage carrying capacity by both departmental and hired vehicles is illustrated in Annexure 6.2.

6.2.5 Maximum and Minimum Trip Limits of Departmental Vehicles

Primarily based on the distance between borough to disposal site Dhapa, concentration of waste generation points and accessibility of vehicles to the collection points, the KMC area are divided into two zones, zone 1 and zone 2. Borough 2 to borough 8 and borough 12 fall under zone1 and Borough 1, borough 9 to borough 11 and borough 13 to borough 15 fall under zone 2. Borough wise distance and their zones are mentioned in Table 6.16 **(Chattopadhyay et al. 2009)**.

Table 6.16 Borough wise distance and their zones for disposal site Dhapa

Zone 1 (near to dumpsite)	Distance from Dhapa disposal site (KM)	Zone 2 (away from dumpsite)	Distance from Dhapa disposal site (KM)
Borough 2	7.5	Borough 1	9.0
Borough 3	5.0	Borough 9	9.5
Borough 4	7.5	Borough 10	7.0
Borough 5	7.0	Borough 11	8.0
Borough 6	7.0	Borough 13	10.0
Borough 7	3.5	Borough 14	11.5
Borough 8	6.5	Borough 15	13.5
Borough 12	3.0		

For departmental vehicles maximum and minimum trip limits are considered. Each running departmental vehicles has to make minimum trips. Incentives are given to the drivers and helpers for carrying wastes more than the minimum trip but up to the maximum trip limit. Maximum and minimum trip limits and incentive of departmental vehicles are shown in Table 6.17.

Table 6.17 Maximum and minimum trip limits of departmental vehicles for different zones and their incentive

Type of departmental vehicles	Zone 1		Zone 2		Capacity (MT)	Incentive rate per ton (Rs / MT)
	Max. trip	Min. trip	Max. trip	Min. trip		
DD1 (1 driver and 1 helper)	6	3	6	2	1.75	15
DD2 (1 driver and 1 helper)	8	3	6	2	2	10.5
DD3 (1 driver and 4 helper)	8	3	4	2	3	35
DD4 (1 driver and 1 helper)	8	3	4	2	7	7.5

Note: Total incentive rate (Rs / MT) = (Incentive rate of Driver, Rs / MT) + (Incentive rate of Helper, Rs / MT) × No. of Helper

6.2.6 Cost of Transportation

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the treatment and disposal site. Transportation cost of departmental vehicles is the summation of fuel cost, fixed running cost and fixed idle cost. KMC is responsible for procurement, operation and maintenance of its departmental vehicles.

6.2.6.1 Cost of transportation for departmental vehicles

(a) Fuel Cost

Up and down (i.e. loaded trip and unloaded trip) distance for each trip is considered same for each borough as the distances are calculated from central of borough to Dhapa dumpsite. Average waste carrying capacity, varying fuel consumption for loaded and empty run condition i.e. different fuel costs in loaded and empty run conditions for different vehicles are shown in Table 6.21. Fuel cost per ton of waste transportation for different type of vehicles for different boroughs to Dhapa is estimated based on the Table 6.18 and shown in Table 6.19. A summary of the results from Table 6.19 is given in Table 6.20.

Table 6.18 Average load carrying capacity, fuel consumption and cost in loaded and empty run condition for departmental vehicles

Type of vehicles	Avg. weight carried (MT/day)	Fuel consumption in loaded run condition (KM /Lit)	Fuel consumption in empty run condition (KM /Lit)	Fuel cost per KM in loaded run condition (Rs/KM)	Fuel cost per KM in empty run condition (Rs/KM)
DD1	1.75	4.25	5.5	8.00	6.18
DD2	2	3.5	4.5	9.71	7.56
DD3	3	3.35	4.35	10.15	7.82
DD4	7	1.67	2.33	20.36	14.59

Note: Fuel consumption cost in loaded run condition (Rs/KM) = Fuel cost (Rs/Lit) / Fuel consumption in loaded run condition (KM/Lit). Fuel cost is taken Rs. 34 per liter (KMC, 2007).

Table 6.19 Per MT fuel cost of waste transportation from different boroughs to Dhapa (East dumpsite)

Deptt. Vehicle	Fuel charge		Borough-1			Borough-2		
	Loaded (Rs\km)	Unloaded (Rs\km)	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)
DD1	8	6.18	9	127.62	72.926	7.5	106.35	60.771
DD2	9.71	7.56	9	155.43	77.715	7.5	129.53	64.765
DD3	10.15	7.82	9	161.73	53.91	7.5	134.78	44.927
DD4	20.36	14.59	9	314.55	44.936	7.5	262.13	37.447

Sample calculation: DD2: (9.71+7.56) X 9 = 155.43 (considering up and down distances); 155.43/2(av. carrying capacity) = 77.715

Deptt. Vehicle	Borough-3			Borough-4			Borough-5		
	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)
DD1	5	70.9	40.514	7.5	106.35	60.77	7	99.26	56.72
DD2	5	86.35	43.175	7.5	129.53	64.765	7	120.89	60.45
DD3	5	89.85	29.95	7.5	134.78	44.927	7	125.79	41.93
DD4	5	174.75	24.964	7.5	262.13	37.447	7	244.65	34.95

Deptt. Vehicle	Borough-6			Borough-7			Borough-8		
	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)
DD1	7	99.26	56.72	3.5	49.63	28.36	6.5	92.17	52.668
DD2	7	120.89	60.45	3.5	60.45	30.225	6.5	112.26	56.13
DD3	7	125.79	41.93	3.5	62.90	20.97	6.5	116.81	38.397
DD4	7	244.65	34.95	3.5	122.33	17.476	6.5	227.18	32.454

Table 6.19 Per MT fuel cost of waste transportation from different boroughs to Dhapa (East dumpsite)

Deptt. Vehicle	Borough-9			Borough-10			Borough-11		
	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)
DD1	9.5	134.71	76.977	7	99.26	56.72	8	113.44	64.823
DD2	9.5	164.07	82.035	7	120.89	60.445	8	138.16	69.08
DD3	9.5	170.72	56.907	7	125.79	41.93	8	143.76	47.92
DD4	9.5	332.03	47.433	7	244.65	34.95	8	279.60	39.943

Deptt. Vehicle	Borough-12			Borough-13			Borough-14		
	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)	Distance (km)	Cost (Rs)	Cost/ton (Rs)
DD1	3	42.54	24.31	10	141.80	81.03	11.5	163.07	93.183
DD2	3	51.81	25.905	10	172.70	86.35	11.5	198.61	99.305
DD3	3	53.91	17.97	10	179.70	59.90	11.5	206.67	68.89
DD4	3	104.85	14.987	10	349.50	49.93	11.5	401.93	57.418

Deptt. Vehicle	Borough-15		
	Distance (km)	Cost (Rs)	Cost/ton (Rs)
DD1	13.5	191.43	109.388
DD2	13.5	233.15	116.575
DD3	13.5	242.60	80.867
DD4	13.5	471.83	67.404

Table 6.20 Fuel cost per ton for departmental vehicles for Dhapa (East dumpsite)

Borough	Cost/ton for DD1 vehicle	Cost/ton for DD2 vehicle	Cost/ton for DD3 vehicle	Cost/ton for DD4 vehicle
Borough 1	72.93	77.72	53.91	44.94
Borough 2	60.77	64.77	44.93	37.45
Borough 3	40.51	43.18	29.95	24.96
Borough 4	60.77	64.77	44.93	37.45
Borough 5	56.72	60.45	41.93	34.95
Borough 6	56.72	60.45	41.93	34.95
Borough 7	28.36	30.23	20.97	17.48
Borough 8	52.67	56.13	38.94	32.45
Borough 9	76.98	82.04	56.91	47.43
Borough 10	56.72	60.45	41.93	34.95
Borough 11	64.82	69.08	47.92	39.94
Borough 12	24.31	25.91	17.97	14.98
Borough 13	81.03	86.35	59.90	49.93
Borough 14	93.18	99.31	68.89	57.42
Borough 15	109.39	116.58	80.97	67.40

(b) Fixed cost for departmental vehicles

Fixed running cost for departmental vehicles DD1, DD2, DD3 and DD4 are calculated on the basis of depreciation (assuming scrap value 10% of capital cost, life of vehicle as 10 years), interest (10% on reducing loan), wages of driver and helper [Basic, Dearness Allowances (D.A.), House Rent Allowances (H.R.A), Medical Allowances (M.A) including 30% overtime allowances)], wages of garage staff including managerial and administration, annual operational and maintenance costs (10% of capital cost). For the calculation of fixed idle cost, wages of driver and helper are not considered, as optimised numbers of drivers and helpers are available which is almost used regularly by the running vehicles. Different types of number of running and idle vehicles and their fixed and idle costs are shown in Table 6.21 below:

Table 6.21 Summary of number of running and idle departmental vehicles per day and fixed running cost and fixed idle cost per day (as in 2007)

Type of vehicles	**Total no. of vehicles**	**Running vehicle**	**Idle vehicle**	**Fixed cost for each running vehicle / day in Rs**	**Fixed cost for each Idle vehicle / day in Rs**
4.5 m3 Dumper Placer (DD1)	16	9(56.25%)	7	2029.19	1388.10
7.0 m3 Dumper Placer (DD2)	73	34(46.57%)	39	2167.69	1526.59
8.0 m3 Tipper Truck (DD3)	82	55(67.07%)	27	2625.39	1214.99
11.0 m3 Tipper Truck (DD4)	28	12(42.85%)	16	3180.18	2282.64

6.2.6.2 Cost of transportation for hired vehicles

Since hired vehicles carry garbage and silt/rubbish separately, therefore, transportation cost (Rs / MT) for hired vehicles are considered for silt/rubbish and garbage separately for different zones of Dhapa dumpsite and shown in Table 6.22. Carrying capacity of garbage and silt/rubbish for hired vehicle are considered as 7 MT/trip and 9 MT/trip respectively, although in 2007 not all hired vehicles were payloader-loaded. Hired vehicle can go 3.25 km per litre of oil in loaded condition and 4.25 km per litre of oil in unloaded condition.

Table 6.22 Cost per ton for garbage and silt transportation to Dhapa by hired vehicles

Borough	**Area in each borough (km2)**	**Zone**	**Cost of garbage transportation as per weighted area (Rs / MT)**	**Cost of silt transportation as per weighted area (Rs / MT)**
1	9.736	2	153	143
2	3.240	1	144	134
3	9.090	1	133.50	123.50
4	3.310	1	142	132
5	5.490	1	140	130
6	5.590	1	132.50	122.50
7	25.430	1	147.75	137.75
8	9.740	1	140	130
9	18.950	2	156.70	146.70
10	15.10	2	148.30	138.30
11	11.67	2	157.80	147.80
12	28.54	1	154.30	144.30
13	11.46	2	159.40	149.40
14	17.07	2	160	150
15	8.67	2	160	150

6.2.7 Sorting and recycling

Recyclable materials generated in Kolkata at the household-level are recovered exclusively through an informal, market driven, recycling collection and processing system. In the informal system, high value, good quality materials and items such as rigid plastics, newspaper, metal, furniture etc. are typically purchased directly from waste generators by traders. These materials do not enter the KMC waste stream. Manual scavengers recover a portion of these by rummaging through waste temporarily stored at secondary collection points located throughout the city (vats), and this recyclable amount is estimated as 5%.

At the landfill site, Dhapa, a group of rag pickers sorted out the recyclable materials in a regular basis which is estimated as ~ 4.21%. So, in the existing system 9.21% of recyclable materials are recycled by rag pickers through this informal system of scavenging at vats and at the disposal facility. Since all these recycling systems are done in informal way therefore, no revenue is earned by the municipal authority.

6.2.8 Composting

Compost plant exists near Dhapa disposal site — most of the time compost plant runs with 150 MT/day. So, from model validation for the existing system compost processing is considered as 150 MT/day. Since compost plant is run through PPP model so no cost of compost production is borne by KMC that means total cost of compost is considered as zero.

6.2.9 Revenue from compost

It is assumed that KMC gets Rs.87.50 as royalty per MT of compost sold.

6.2.10 Incineration

For existing system in 2007, no incineration is considered.

6.2.11 Landfilling

Operational and maintenance cost of open dumping system is calculated on the basis of

- establishment cost (general, skilled, administration/management, miscellaneous, contingency)
- capital and maintenance cost (fixed equipment, mobile equipment, spare parts for bull dozers, fuel, supply of trip tokens, ribbons etc),
- cost of utilities (power and utilities, miscellaneous, contingency).

Amount of O&M cost of open dumping system is considered as Rs. 95/- per ton.

6.2.12 Model validation

The optimisation problem was solved on a computer (Intel Pentium Dual-Core processor having 1.86 GHz processor speed) using LINGO v 9.0 (LINDO Systems Inc.) optimisation software package on Windows 10 platform. Annexure 6.3 shows some of the datasets used by LINGO for validation run. SWM system of Kolkata existing in 2007 is not model-optimised. For model validation, costs, availability of vehicles, waste transported by different vehicles and other parameters of MSW management system are compared with the model results of the 2007 MSW management situation.

(a) Waste quantities shared by individual vehicles in different boroughs

On running the model, the amount of waste (silt + garbage) disposal for different boroughs by different vehicle types came out as depicted in Table 6.23 and Figure 6.5

Table 6.23 Table showing amount of waste transported by different vehicles from boroughs

	WASTE TRANSPORTED BY VEHICLES IN MT					
Borough No.	**DD1**	**DD2**	**DD3**	**DD4**	**HH**	**Borough Wisetotal for dept. vehicles**
1	1.784	42.8256	32.1192	28.5504	93.27	105.2792
2	0	43.78	31.5216	0	111.848	75.3016
3	7.179	57.4336	39.4856	0	95.4716	104.0984
4	0	31.246	1.5623	48.4313	87.7104	81.2396
5	0	15.0784	0	73.5072	117.034	88.5856
6	0	16.3954	0	53.8706	199.094	70.266
7	0	36.228	0	43.4736	224.368	79.7016
8	0	40.0975	35.2858	0	125.087	75.3833
9	0	45.22	66.50	0	180.20	111.72
10	0	77.4916	0	0	290.348	77.4916
11	23.865	0	19.092	0	54.303	42.957
12	25.062	0	20.885	0	39.843	45.947
13	23.556	0	54.964	0	82.46	78.52
14	6.464	0	38.781	0	93.3955	45.2445
15	0	0	1.1092	0	21.1318	1.10915
TOTAL	87.909	405.796	341.3057	247.833	1815.56	1082.8446

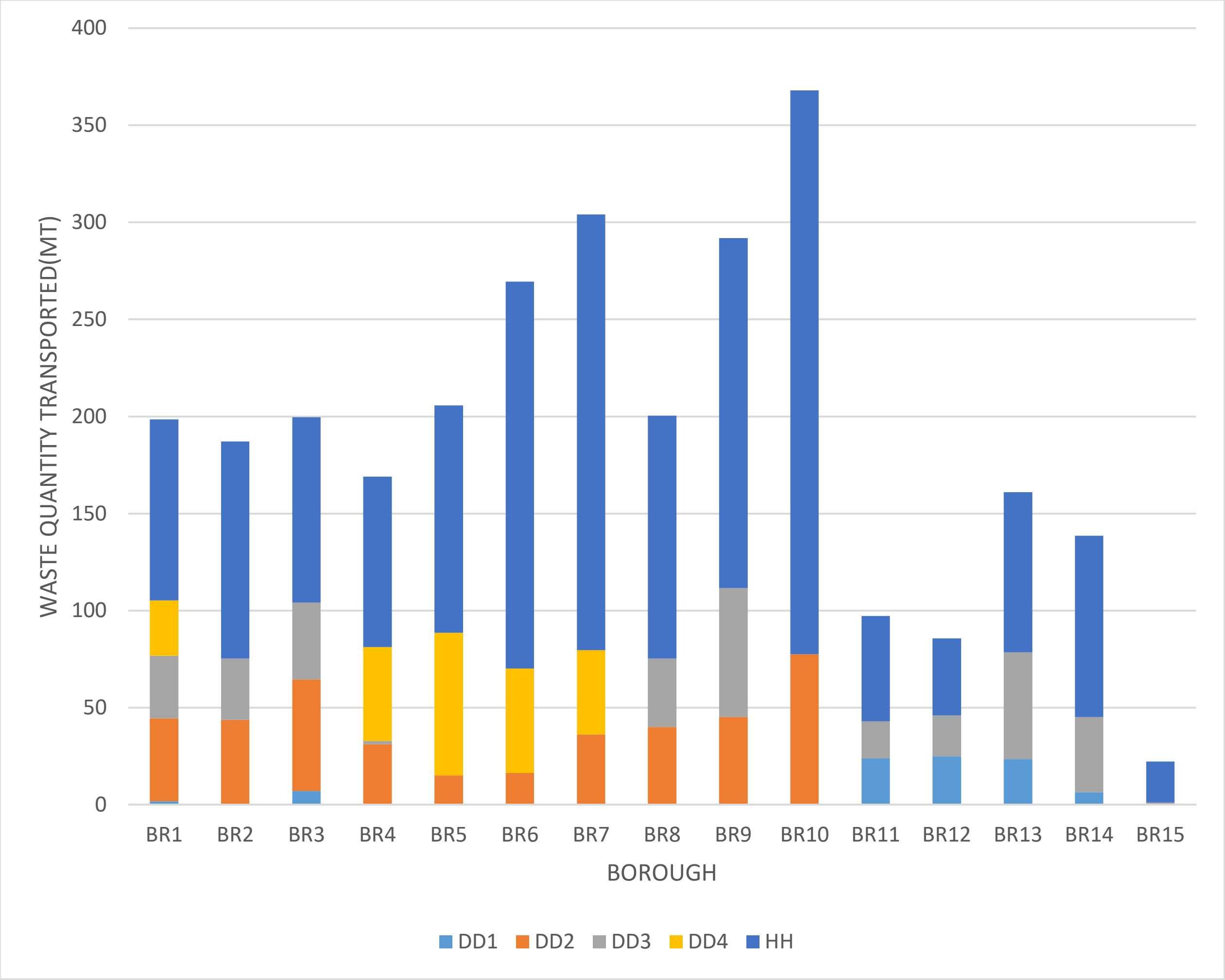

Figure 6.5 Figure illustrating amount of waste transported by different vehicles from boroughs

(b) Borough wise waste quantity carried by departmental and hired vehicles

Quantity of garbage and silt or rubbish carried by departmental vehicles and hired vehicles for different boroughs is shown in Figure 6.6. According to the existing waste carrying limit and waste carrying costs, departmental vehicles carry more wastes in borough 1, borough 3 and borough 12 where as in other boroughs hired vehicles transport more than the departmental vehicles. In borough 6 and borough 7, department carries only ~26%, and in case of borough 10 and borough 15 departmental vehicle transports only ~21% and ~5.00% respectively. On an average in other boroughs departmental vehicles carry waste in between 42% to 55%.

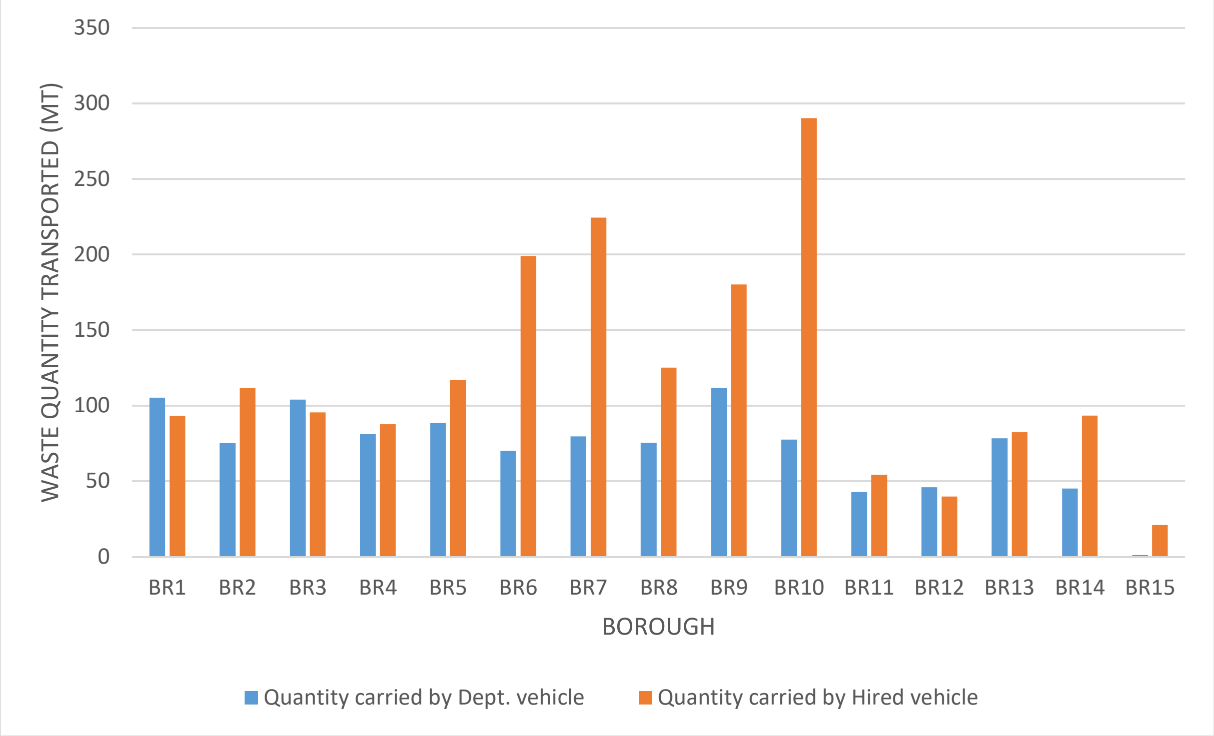

Figure 6.6 Borough wise waste quantity shared by departmental and hire vehicles

(c) Total waste quantity carried by departmental and hired vehicles

Percentage share of the total transportation of waste by different type of departmental vehicles (like DD1, DD2, DD3, DD4) and hired vehicles (HH) are 3.03%, 14.00%, 11.8%, 8.55% and 62.64% , shown in Figure 6.7.

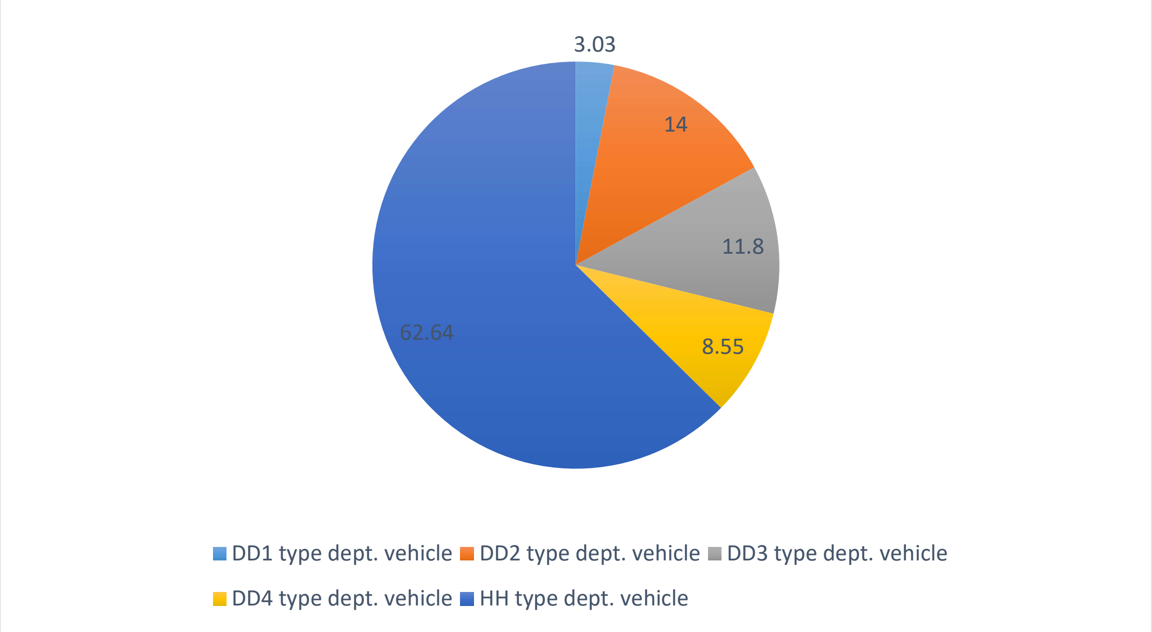

Figure 6.7 Shared quantity of waste (percentage) by departmental and hired vehicles

As per 2007 KMC records, ratio of total quantity of waste (i.e. garbage + silt/rubbish) transported by departmental and hired vehicles is 33:67. But model provides a ratio of 37:63. If garbage disposal only is considered, then model prefers a ratio of 42:58 as against KMC record of 37:63. Thus, the model, prefers 5% excess waste transportation by departmental vehicles as their variable portion (fuel + incentive costs) of transportation cost is less than the transportation cost of hired vehicles.

(d) Total transportation and O&M cost of departmental and hired vehicles

Total cost of departmental vehicles includes fixed running cost, fixed idle cost, incentive cost and fuel cost.

(i) Fixed running cost and fixed idle cost of departmental vehicles

Fixed running cost for DD4 type vehicle is highest (Ref Table 6.21) if compared each type of vehicles individually but in total as a whole fixed running cost for DD3 vehicle is maximum (Table 6.21) as highest number (55 numbers) of DD3 vehicles are in running condition (Table 6.21). Fixed idle cost for DD4 type vehicle is least if compared individually but in totality fixed idle cost for DD2 vehicle is maximum (Table 6.24) as highest number (39 numbers) of DD2 vehicles are in idle condition (Table 6.21) in garages .Total fixed running cost and total fixed idle cost for departmental vehicle are shown in Table 6.24 and Figure 6.8.

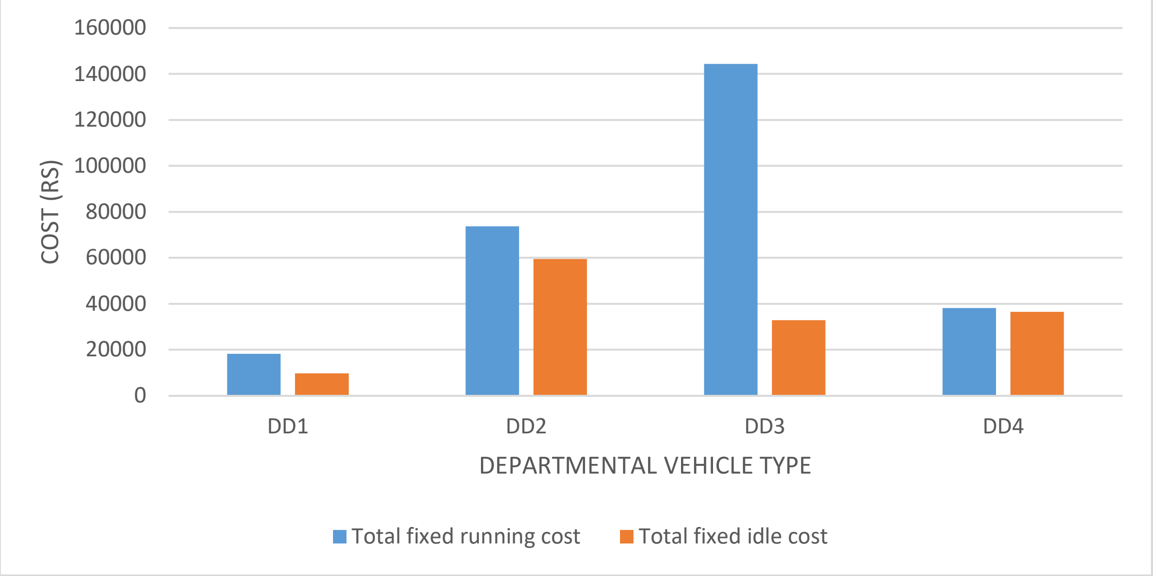

Figure 6.8 Total fixed running and fixed idle cost of different types of departmental vehicles

Table 6.24 Total fixed running and fixed idle cost of departmental vehicle

Dept. vehicle	Total fixed running cost	Total fixed idle cost
DD1	18262.71	9716.700
DD2	73701.46	59537.01
DD3	144396.4	32804.73
DD4	38162.16	36522.24

(ii) Incentive cost

Variation of total incentive cost (Rs.) required per day for departmental vehicles are shown in Table 6.25. Incentive rate per ton (Rs/ton) is maximum for DD3 vehicle (Table 6.17) so model minimizes the total incentive amount of DD3 vehicles. Though DD4 has the minimum incentive rate, as the number of DD4 vehicle is less it does not affect much on its total incentive value. DD4 having the 2nd lowest incentive value and higher number of running vehicles results highest incentive amount.

Table 6.25 Incentive cost of departmental vehicles per day

Departmental vehicle	Total incentive (Rs)
DD1	846.1515
DD2	2832.859
DD3	395.6978
DD4	598.7482

Model generates total incentive cost of Rs 4,673.46 for departmental vehicles which is less than the actual cost (Rs. 6,600, KMC 2007 data). The difference may be due to mismanagement of the monitoring system, and due to emergency night services rendered in certain cases by departmental staff.

(iii) Fuel cost

Variation of total fuel cost (Rs.) required per day for departmental vehicles are shown in Table 6.26.

Table 6.26 Fuel cost of departmental vehicles per day

Departmental vehicle	Total fuel cost (Rs)
DD1	5088.204
DD2	24308.65
DD3	16902.55
DD4	8308.132

Total actual fuel cost incurred for departmental vehicles was aroundRs.1,20,000/day (KMC 2007 data) which is more than twice the value provided by the model (~Rs. 55,000/day). This is expected, since the model optimises vehicle routing and scheduling while fuel pilferage is suspected for departmental vehicles in real-life.

Now for the context of the total transportation cost, the departmental vehicle DD1, DD2, DD3 and DD4 carries ~8.1%, ~37.5%, ~31.5% and ~22.9% of total quantity of waste carried by departmental vehicles and variation of their respective total cost are ~ 7.2%, ~34%, 41% and 17.8% respectively (Table 6.27). DD3 vehicle carries less quantity of waste than DD2 vehicles but total transportation cost of DD3 is more than DD2 due to more number of vehicles in operation and engagement of higher number of helpers for DD3 type manually loaded vehicle (Table 6.21). In case of payloader loaded DD4 type vehicles though the fixed cost is high yet less number of operating vehicles and higher carrying capacity results comparatively lesser total transportation cost than DD2 and DD3 type vehicles.

Table 6.27 Waste quantity carried and its transportation costs for different departmental vehicles

Departmental vehicle type	**Quantity of waste carried (TPD)**	**Total transportation cost (Rs)**
DD1	87.9101	33067.65
DD2	405.7969	157546.90
DD3	340.6421	194050.46
DD4	247.8331	83477.53

Comparison of fuel cost, fixed running cost, fixed idle cost, incentive cost and total transportation cost for D1, D2, D3 and D4 type vehicle are shown in figure 6.9.

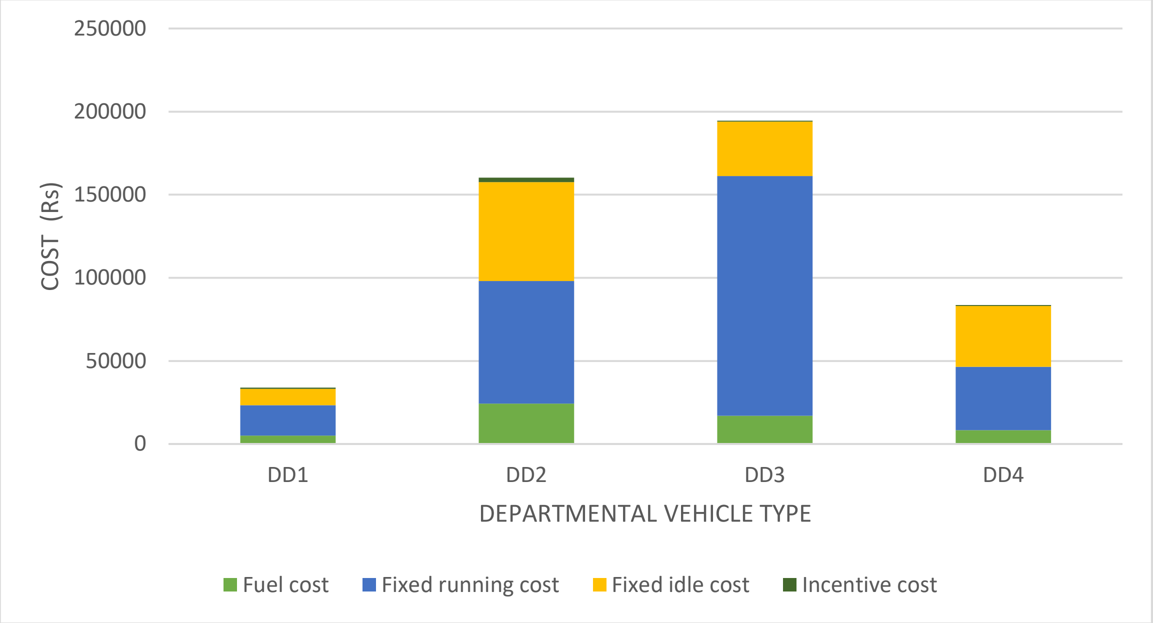

Figure 6.9 Different components of waste transportation costs for different types of departmental vehicles

The transportation cost of hired vehicle, which are removal cost of garbage, silt or rubbish and total waste for hire vehicles is shown in Table 6.28. 85% cost (of total waste carrying cost of hired vehicles) is incurred to remove 84% garbage quantities and 15% cost is incurred to remove 16% silt or rubbish.

Table 6.28 Transportation costs of hired vehicles carrying garbage and silt or rubbish

Vehicle type	Cost for garbage (Rs)	Cost for silt (Rs)	Cost for waste (garbage + silt) (Rs)
HH	223864.7	39679.67	263544.3

Model predicts a garbage transportation cost of Rs. 2,23,864.7/day by hired vehicles, which is about 5% lower than actual cost (Rs. 2,36,000/day). The higher value of garbage transportation by hired vehicle is mainly due to higher amount of garbage transportation on regular basis and sometimes accidental services rendered for urgent removal of solid waste.

Total transportation cost (including incentive) for departmental and hired vehicles for actual MSW management system by KMC was Rs 8,15,225.07/day in 2007, while validation model gave Rs. 7,35,928.75/day. Model analysis provides the optimised value for 2007 scenario; so there was an opportunity to minimise transportation costs by about 10%.

Figure 6.10 shows that ~ 64.2% of the total transportation cost is incurred for departmental vehicles to remove ~ 37% of total waste quantities whereas for hired vehicles ~ 35.8% cost is incurred to remove ~ 63% of total waste quantities.

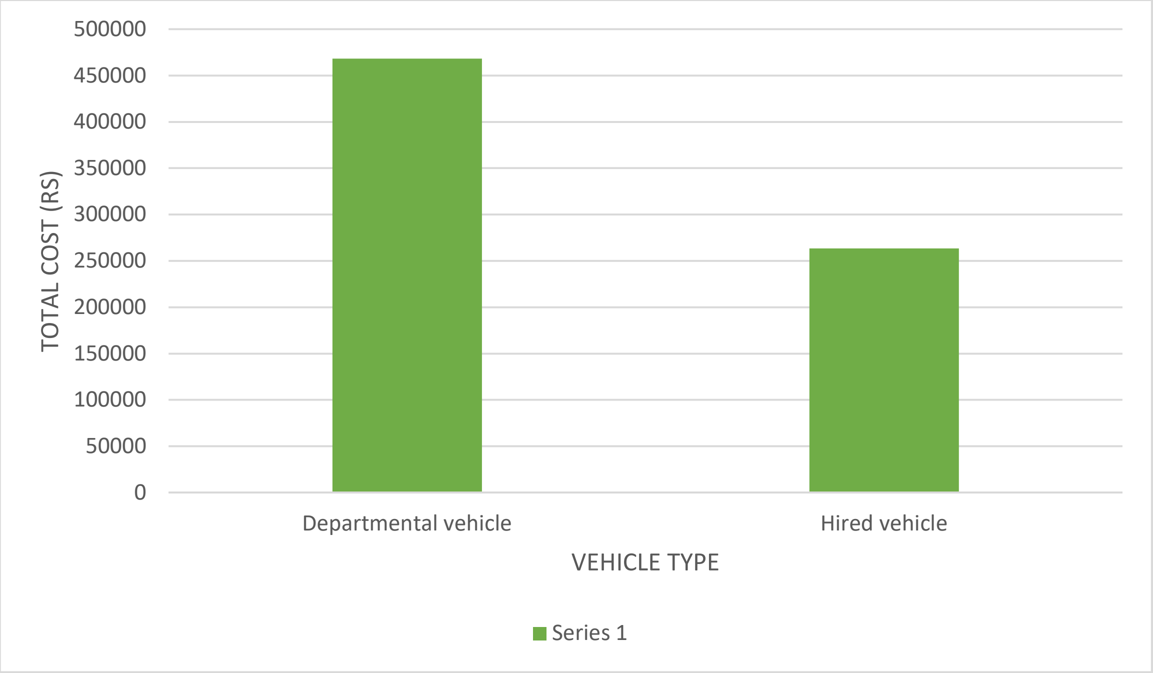

Figure 6.10 Total transportation cost comparison for departmental and hired vehicles

Considering all expenditure, cost per ton of waste removal by hire vehicles is less compared to departmental vehicles having higher fixed cost and incentive cost.

Actual revenue earned by KMC in 2007 as royalty from sale of compost is same as predicted by the model (Rs. 3,510.56/day). Cost comparison of model analysis for MSW management for year 2007 and actual cost incurred in 2007 by KMC for SWM system is shown in Table 6.29.

Table 6.29 Table showing comparison between actual cost in 2007 and model-predicted cost

Individual items	**Cost (as given by optimisation model) (Rs./day)**	**Cost (in actual situation) (Rs./day)**	**Cost variation (%) in model compared to actual situation**
Cost of transportation including incentives	7,35,928.75	8,15,225.07	9.73% decrease
Revenue from compost	3,510.56	3,510.56	0%
Cost of landfill	2,53,498.80	2,55,153.42	0.64% decrease
Total expenditure	9,86,836.1	10,66,867.93	7.5% decrease

The above validation of the existing model shows very good results and also indicates 7.5% cost minimisation was possible during 2007. So, the basic model can be used for further analysis.

6.3 ANALYSING VARIOUS SCENARIOS WITH THE FUTURISTIC ISWM WITH TRANSFER STATION

In chapter 5, an ISWM system has been modeled and in sub-chapter 6.2, application of the model to KMC area has been shown. In this sub-chapter 6.3, analysis is being done subsequent to the introduction of transfer stations in between the route from borough collection points to the disposal site. Three transfer stations are located, each transfer station associated with a particular disposal site. We will analysis the model by selecting the transfer station midway between disposal site and KMC area. It is assumed that along with the transfer station, there will be sorter, incinerator and composting plant; the landfill sites will, however, be located at the original disposal sites. No extra land cost for setting up of incinerator and composting plant need to be accounted for, since land cost is already incorporated in the operational costs of incinerator and composting plant — only their locations have shifted from disposal site to transfer station. Garbage portion from the city will enter the processing plants and then the disposable waste (includes process rejects/residues, ash, inert, etc) will be transferred from transfer station to disposal sites (landfill sites) for landfilling by TATA LPT 2518 Heavy Duty trucks. Silt/inert/rubbish may be directly loaded to TATA LPT 2518 trucks and transferred to landfill site. Since the incinerator plants generate electricity (thus earning revenue), locating the transfer station (along with incinerator) near KMC boundary will make power transmission / distribution to consumers easier and cheaper. Similarly, clubbing the composting plant along with the transfer station will make marketing and selling of compost to the nearby agricultural areas easier. Again, if the transfer stations are at midway between KMC area and disposal sites (landfill sites), then impact of pollution, if any, from the processing plants on the city, will be less. Due to the introduction of the transfer station, the modeling equations need to be modified, since fuel cost, fixed running and fixed idle cost of the Heavy Duty Trucks have to be taken into account. Cost of transfer station is ignored, since no equipment or processing is expected there.

Equation (49) needs to be modified to —

Total cost of transportation of wastes:

$$CTRANSP - ctchh - \sum_{dd=1}^{DD} ctcdd_{dd} - ctctrucks = 0$$

ctctrucks is the total cost of transporting disposable waste from transfer station to the disposal site landfills by the heavy duty trucks.

The following equations need to be appended:

Total cost of transporting waste from transfer station to the respective disposal site (landfill) *d* by the heavy duty trucks:

$$ctctrucks - cfueltruckstot - cfxdrtruckstot - cfxditruckstot = 0 \qquad (59)$$

cfueltruckstot is the fuel cost of the heavy duty trucks used for transporting disposable waste from transfer station to disposal site landfills. Similarly, *cfxdrtruckstot* and *cfxditruckstot* are the fixed running cost and idle cost respectively of the heavy duty trucks.

Total fuel cost of the heavy duty trucks:

$$cfueltruckstot - \sum_{d=1}^{D} xf_d \times fc\_t_d = 0 \qquad (60)$$

fc_t_d is the fuel cost per ton of waste transported by heavy duty trucks from transfer station associated with disposal site *d* to disposal site (landfill) *d* (Rs/MT).

Total fixed running cost of heavy duty trucks:

$$cfxdrtruckstot - t\_na \times t\_rc = 0 \qquad (61)$$

t_na is the number of heavy duty trucks actually running considering all the three disposal sites. t_rc is the fixed running cost per truck.

Total fixed idle cost of heavy duty trucks:

$$cfxditruckstot - (t\_no - t\_na) \times t\_ic = 0 \qquad (62)$$

t_no is the total number of heavy duty trucks considering all the three disposal sites. t_icis the fixed idle cost per truck.

Number of trips per day for each heavy duty truck associated with disposal site *d*:

$$xf_d \leq trips\_truck_d \times no\_trucks_d \times cap\_truck \qquad \forall d = 1,2,3 \ldots D \quad (63)$$

$trips\_truck_d$ is the number of trips per day each heavy duty truck associated with disposal site (and transfer station) *d* is required to make. no_trucks_d is the number of heavy duty trucks associated with disposal site (and transfer station) *d*. cap_truck is the payload capacity of a heavy duty truck (MT).

Total number of running heavy duty trucks:

$$\sum_{d=1}^{D} no\_trucks_d - t\_na = 0 \qquad (64)$$

RUN 1:

6.3.1 Transfer station located very near/inside KMC boundary

In this model we are taking our transfer station location from the research paper of **(Paul et al. 2017)**. Where he found the transfer station location near the KMC boundary by GIS. The East transfer station is located at Uttarpanchanna Gram (22°32′02" N,88°23′50"E), near Science City, North transfer station at Ghughudanga-Pearabagan(22°37′11" N, 88°23′38"E) and South transfer station at Kabardanga, Ramchandrapur(22°27′39" N, 88°20′01"E) on Nepalgunje-Julpia Road, respectively **(Paul K. et al. 2017)**. The conditions and all other constraints are given below.

6.3.1.1 Borough-Zones associated with transfer station/disposal sites

The borough zone divisions and the distances of the borough centres to the transfer stations are shown in Table 6.30, 6.34 and 6.35 **(Paul K. et al. 2017)**.

Table 6.30. Borough wise distance and their zones (E disposal site/Transfer Station)

Zone 1	**Distance from East Transfer Station (Km)**	**Zone 2**	**Distance from East Transfer Station (Km)**
Borough 3	7.03	Borough 1	10.92
Borough 4	7.67	Borough 2	8.74
Borough 5	6.45	Borough 9	9.04
Borough 6	5.94	Borough 11	10.24
Borough 7	1.65	Borough 13	11.52
Borough 8	5.195	Borough 14	14.00
Borough 10	8.07	Borough 15	15.98
Borough 12	4.03		

Table 6.31. Borough wise distance and their zones (N disposal site/Transfer Station)

Zone 1	**Distance from North Transfer Station (Km)**	**Zone 2**	**Distance from North Transfer Station (Km)**
Borough 1	2.14	Borough 8	12.9
Borough 2	4.50	Borough 9	14.34
Borough 3	7.11	Borough 10	16.77
Borough 4	6.03	Borough 11	19.47
Borough 5	7.34	Borough 12	16.69
Borough 6	9.08	Borough 13	19.07
Borough 7	11.32	Borough 14	19.88
		Borough 15	20.25

Table 6.32. Borough wise distance and their zones (S disposal site/Transfer Station)

Zone 1	**Distance from South Transfer Station (Km)**	**Zone 2**	**Distance from South Transfer Station (Km)**
Borough 8	8.03	Borough 1	18.39
Borough 9	8.994	Borough 2	15.85
Borough 10	6.165	Borough 3	16.77
Borough 11	4.796	Borough 4	14.99
Borough 12	11.19	Borough 5	13.17
Borough 13	3.54	Borough 6	12.34
Borough 14	6.85	Borough 7	12.31
		Borough 15	16.30

Note: Zone 1: Boroughs near to transfer station; Zone 2: Boroughs far from transfer station

6.3.1.2 Borough-wise garbage and silt/rubbish generation

Same as Table 6.13 of sub chapter 6.1.10

6.3.1.3 Types of vehicles for transportation of waste

Same as sub chapter 6.1.11

6.3.1.4 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Same as Table 6.14 of sub chapter 6.1.12

6.3.1.5 Maximum and minimum trip limits for departmental vehicles

Same as Table 6.15 of sub chapter 6.1.13

6.3.1.6 Transportation cost

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the transfer station. Additionally, cost of transporting dumpable waste from transfer station to disposal site (landfill site) needs to be considered.

6.3.1.6.1 Cost of transportation for departmental vehicles

(a) Fuel Cost
The total Up and down (i.e. loaded trip and unloaded trip) distance for each trip is considered same for each borough as the distances are calculated from centre of borough to three

disposal sites. Average waste carrying capacity, varying fuel consumption for loaded and empty run condition i.e. different fuel costs in loaded and empty run conditions (in Rs/km) for DD1, DD2, DD3, DD4, DD5, DD6 and HH type hired vehicle is shown in Table 6.33 (Paul K. et al. 2017).The fuel cost per ton for different type of vehicles for different boroughs to the transfer station is estimated based on the Table 6.33 and shown in Table 6.34, Table 6.35 and Table 6.36 for East, North and South transfer stations respectively. A summary of the results from Table 6.34, Table 6.35 and Table 6.36 is given in Table 6.37, Table 6.38 and Table 6.39.

Average waste carrying capacity, varying fuel consumption for loaded and empty run condition and per MT cost of waste transportation for TATA LPT 2518 Heavy Duty Truck is given in Table 6.40, Table 6.41 and Table 6.42(Paul K. et al. 2017).

Table 6.33 Average load carrying capacity, fuel consumption and cost in loaded and empty run condition for departmental vehicles

Type of vehicles	**Avg. weight carried (MT/day)**	**Fuel consumption in loaded run condition (KM /Lit)**	**Fuel consumption in empty run condition (KM /Lit)**	**Fuel cost per KM in loaded run condition (Rs/KM)**	**Fuel cost per KM in empty run condition (Rs/KM)**
DD1	1.75	4.25	5.5	13.37*	10.33
DD2	2	3.5	4.5	16.24	12.63
DD3	7	1.67	2.33	34.04	24.4
DD4	9	1.43	1.67	39.8	34.11
DD5	10	0.909	1.11	63.53	51.16
DD6	**7**	1.25	1.67	45.48	34.04

*Diesel cost Rs. 56.85/ltr. * 13.37= Rs.56.85 /4.25 km*

Table 6.34 Per MT of waste transportation fuel cost from boroughs to **EAST** transfer station for departmental vehicles

Deptt. Vehicle	**Fuel charge**		**Borough-1**			**Borough-2**		
	Loaded (Rs\km)	**Unloaded (Rs\km)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	13.37	10.33	10.92	258.8	147.88	8.74	207.14	118.36
DD2	16.24	12.63	10.92	315.26	157.63	8.74	252.32	126.16
DD3	34.04	24.4	10.92	638.16	91.16	8.74	510.77	72.97
DD4	39.8	34.11	10.92	807.09	89.68	8.74	645.97	71.77
DD5	62.53	51.16	10.92	1241.49	124.15	8.74	993.65	99.37
DD6	45.48	34.04	10.92	868.36	124.05	8.74	695	99.28

Sample Calculation: DD1:
Total to and from cost of transportation = Rs. (13.37+10.33) X 10.92 = Rs.258.8
Per ton cost of transportation = Rs 258.8 / 1.75 = Rs.147.8857

Deptt. Vehicle	**Borough-3**			**Borough-4**			**Borough-5**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	7.03	166.61	95.21	7.67	181.78	103.87	6.45	152.87	87.35
DD2	7.03	202.96	101.48	7.67	221.43	110.71	6.45	186.21	93.11
DD3	7.03	410.83	58.69	7.67	448.23	64.03	6.45	376.94	53.85
DD4	7.03	519.59	57.73	7.67	566.89	62.99	6.45	476.72	52.97
DD5	7.03	799.24	79.92	7.67	872	87.2	6.45	733.3	73.33
DD6	7.03	559.03	79.86	7.67	609.92	87.13	6.45	512.9	73.27

Table 6.34 Per MT of waste transportation fuel cost from boroughs to **EAST** transfer station for departmental vehicles

Deptt. Vehicle	**Borough-6**			**Borough-7**			**Borough-8**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	5.94	140.78	80.45	1.65	39.1	22.34	5.195	123.12	70.35
DD2	5.94	171.49	85.74	1.65	47.64	23.82	5.195	149.98	74.99
DD3	5.94	347.13	49.59	1.65	96.43	13.77	5.195	303.6	43.37
DD4	5.94	439.02	48.78	1.65	121.95	13.55	5.195	383.96	42.66
DD5	5.94	675.32	67.53	1.65	187.59	18.76	5.195	590.62	59.06
DD6	5.94	472.35	67.48	1.65	131.2	18.74	5.195	413.1	59.01

Deptt. Vehicle	**Borough-9**			**Borough-10**			**Borough-11**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	9.04	214.25	122.43	8.07	191.26	109.29	10.24	242.69	138.68
DD2	9.04	260.98	130.49	8.07	232.98	116.49	10.24	295.63	147.82
DD3	9.04	528.3	75.47	8.07	471.61	67.37	10.24	598.43	85.49
DD4	9.04	668.14	74.24	8.07	596.45	66.27	10.24	756.84	84.09
DD5	9.04	1027.76	102.76	8.07	917.48	91.75	10.24	1164.19	116.42
DD6	9.04	718.86	102.69	8.07	641.73	91.68	10.24	814.28	116.32

Table 6.34 Per MT of waste transportation fuel cost from boroughs to **EAST** transfer station for departmental vehicles

Dept. Vehicle	**Borough-12**			**Borough-13**			**Borough-14**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	4.03	96.61	54.58	11.52	273.02	156.01	14	327.18	186.96
DD2	4.03	116.34	58.17	11.52	332.58	166.29	14	404.18	202.09
DD3	4.03	235.51	33.64	11.52	673.23	96.17	14	818.16	116.88
DD4	4.03	297.86	33.09	11.52	851.44	94.6	14	1034.74	114.97
DD5	4.03	458.17	45.82	11.52	1309.7	130.97	14	1591.66	159.17
DD6	4.03	320.47	45.78	11.52	916.07	130.87	14	1113.28	159.04

Deptt. Vehicle	**Borough-15**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	15.98	378.73	216.42
DD2	15.98	461.34	230.67
DD3	15.98	933.87	133.41
DD4	15.98	1181.08	131.23
DD5	15.98	1816.77	181.68
DD6	15.98	1270.73	181.53

Table 6.35 Per MT of waste transportation fuel cost from boroughs to **NORTH** transfer station for departmental vehicles

Deptt. Vehicle	**Fuel charge**		**Borough-1**			**Borough-2**		
	Loaded (Rs\km)	**Unloaded (Rs\km)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	13.37	10.33	2.14	50.72	28.98	4.5	106.65	60.94
DD2	16.24	12.63	2.14	61.78	30.89	4.5	129.91	64.95
DD3	34.04	24.4	2.14	125.06	17.86	4.5	262.98	37.57
DD4	39.8	34.11	2.14	158.17	17.57	4.5	332.59	36.96
DD5	62.53	51.16	2.14	243.29	24.33	4.5	511.6	51.16
DD6	45.48	34.04	2.14	170.17	24.3	4.5	357.84	51.12

Sample Calculation: DD1:
Total to and fro cost of transportation = Rs. (13.37+10.33) X 2.14 = Rs.50.718
Per ton cost of transportation = Rs. 50.718 / 1.75 = Rs.28.98171

Deptt. Vehicle	**Borough-3**			**Borough-4**			**Borough-5**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	7.11	168.5	96.28	6.03	142.91	81.66	7.34	173.96	99.40
DD2	7.11	205.26	102.63	6.03	174.08	87.04	7.34	211.9	105.95
DD3	7.11	415.5	59.36	6.03	352.393	50.34	7.34	428.95	61.28
DD4	7.11	525.5	58.39	6.03	352.39	39.16	7.34	542.5	60.28
DD5	7.11	808.33	80.83	6.03	685.55	68.56	7.34	834.48	83.45
DD6	7.11	565.39	80.76	6.03	479.5	68.5	7.34	583.68	83.38

Table 6.35 Per MT of waste transportation fuel cost from boroughs to **NORTH** transfer station for departmental vehicles

Deptt. Vehicle	**Borough-6**			**Borough-7**			**Borough-8**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	9.08	215.196	122.96	11.32	268..28	153.30	12.9	305.73	174.70
DD2	9.08	262.147	131.07	11.32	326.8	163.4	12.9	372.42	186.21
DD3	9.08	530.63	75.804	11.32	661.54	94.505	12.9	753.87	107.69
DD4	9.08	671.1	74.57	11.32	836.66	92.96	12.9	953.44	105.94
DD5	9.08	1032.3	103.23	11.32	1286.97	128.7	12.9	1466.6	146.66
DD6	9.08	722.04	103.15	11.32	900.17	128.59	12.9	1025.8	146.54

Deptt. Vehicle	**Borough-9**			**Borough-10**			**Borough-11**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	14.34	339.86	194.20	16.77	397.45	227.11	19.47	461.44	263.68
DD2	14.34	413.99	206.99	16.77	484.15	242.07	19.47	562.09	281.05
DD3	14.34	838.03	119.72	16.77	980.04	140.00	19.47	1137.83	162.55
DD4	14.34	1059.87	117.76	16.77	1239.47	137.72	19.47	1439.03	159.89
DD5	14.34	1630.31	163.03	16.77	1906.58	190.66	19.47	2213.54	221.35
DD6	14.34	1140.32	162.9	16.77	1333.55	190.5	19.47	1548.25	221.18

Table 6.35 Per MT of waste transportation fuel cost from boroughs to **NORTH** transfer station for departmental vehicles

Deptt. Vehicle	**Borough-12**			**Borough-13**			**Borough-14**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	16.69	395.55	226.03	19.07	451.96	258.26	19.88	471.16	269.23
DD2	16.69	481.84	240.92	19.07	550.55	275.275	19.88	573.94	286.97
DD3	16.69	975.36	139.34	19.07	1114.45	159.21	19.88	1161.78	165.97
DD4	16.69	1233.56	137.06	19.07	1409.46	156.6	19.88	1469.33	163.25
DD5	16.69	1897.48	189.75	19.07	2168.07	216.8	19.88	2260.16	226.01
DD6	16.69	1327.19	189.6	19.07	1516.44	216.64	19.88	1580.86	225.84

Deptt. Vehicle	**Borough-15**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	20.25	479.92	274.24
DD2	20.25	584.62	292.31
DD3	20.25	1183.41	169.06
DD4	20.25	1496.68	166.29
DD5	20.25	2302.22	230.22
DD6	20.25	1610.28	230.04

Table 6.36 Per MT of waste transportation fuel cost from boroughs to **SOUTH** transfer station for departmental vehicles

Deptt. Vehicle	**Fuel charge**		**Borough-1**			**Borough-2**		
	Loaded (Rs\km)	**Unloaded (Rs\km)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	13.37	10.33	18.39	435.84	249.05	15.85	375.65	214.65
DD2	16.24	12.63	18.39	530.92	265.46	15.85	457.6	228.8
DD3	34.04	24.4	18.39	1074.71	153.53	15.85	926.27	132.32
DD4	39.8	34.11	18.39	1359.2	151.02	15.85	1171.47	130.16
DD5	62.53	51.16	18.39	2090.76	209.07	15.85	1801.99	180.2
DD6	45.48	34.04	18.39	1462.37	208.91	15.85	1260.39	180.06

Sample Calculation: DD1:
Total to and fro cost of transportation = Rs. (13.37+10.33) X 18.39 = Rs.435.843
Per ton cost of transportation = Rs 435.843 / 1.75 = Rs.249.0531

Deptt. Vehicle	**Borough-3**			**Borough-4**			**Borough-5**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	16.77	397.45	227.11	14.49	343.41	196.24	13.17	312.13	178.36
DD2	16.77	484.15	242.07	14.49	418.32	209.16	13.17	380.22	190.11
DD3	16.77	980.04	140.00	14.49	846.8	120.97	13.17	769.65	109.95
DD4	16.77	1239.47	137.72	14.49	1070.96	118.99	13.17	973.39	108.15
DD5	16.77	1906.58	190.66	14.49	1647.37	164.74	13.17	1497.29	149.73
DD6	16.77	1333.55	190.5	14.49	1152.24	164.6	13.17	1047.28	147.61

Table 6.36 Per MT of waste transportation fuel cost from boroughs to **SOUTH** transfer station for departmental vehicles

Deptt. Vehicle	**Borough-6**			**Borough-7**			**Borough-8**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	12.34	292.46	167.12	12.31	291.75	166.71	8.03	190.31	108.75
DD2	12.34	356.25	178.13	12.31	355.39	177.69	8.03	231.83	115.91
DD3	12.34	721.15	103.02	12.31	719.39	102.77	8.03	469.27	67.04
DD4	12.34	912.05	101.34	12.31	909.83	101.09	8.03	593.49	65.94
DD5	12.34	1402.93	140.29	12.31	1399.52	139.95	8.03	912.93	91.29
DD6	12.34	981.27	140.18	12.31	978.89	139.84	8.03	638.55	91.22

Deptt. Vehicle	**Borough-9**			**Borough-10**			**Borough-11**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	8.994	213.16	121.80	6.165	146.11	83.49	4.796	113.66	64.95
DD2	8.994	259.66	129.83	6.165	177.98	88.99	4.796	138.46	69.23
DD3	8.994	525.61	75.08	6.165	360.28	51.47	4.796	280.27	40.04
DD4	8.994	664.75	73.86	6.165	455.65	50.62	4.796	354.47	39.38
DD5	8.994	1022.53	102.25	6.165	700.89	70.09	4.796	545.25	54.52
DD6	8.994	715.20	102.17	6.165	490.24	54.47	4.796	381.37	54.48

Table 6.36 Per MT of waste transportation fuel cost from boroughs to **SOUTH** transfer station for departmental vehicles

Deptt. Vehicle	**Borough-12**			**Borough-13**			**Borough-14**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**	**Distance (km)**	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	11.19	265.20	`151.54	3.54	83.89	47.94	6.85	162.34	92.77
DD2	11.19	323.05	161.53	3.54	102.2	51.1	6.85	197.76	98.88
DD3	11.19	653.94	93.42	3.54	206.88	29.55	6.85	400.31	57.18
DD4	11.19	827.05	91.89	3.54	261.64	29.07	6.85	506.28	56.25
DD5	11.19	1272.19	127.21	3.54	402.46	40.25	6.85	778.78	77.87
DD6	11.19	889.83	127.12	3.54	281.5	40.21	6.85	544.71	77.82

Deptt. Vehicle	**Borough-15**		
	Distance (km)	**Cost (Rs)**	**Cost/ton (Rs)**
DD1	16.3	386.31	220.75
DD2	16.3	470.58	235.29
DD3	16.3	952.57	136.08
DD4	16.3	1204.73	133.86
DD5	16.3	1853.15	185.31
DD6	16.3	1296.17	185.17

Table 6.37 Fuel cost per ton for departmental vehicles (E Transfer Station)

Br.	Cost/ton for DD1 vehicle	Cost/ton for DD2 vehicle	Cost/ton for DD3 vehicle	Cost/ton for DD4 vehicle	Cost/ton for DD5 vehicle	Cost/ton for DD6 vehicle
1	147.89	157.63	91.17	89.68	124.15	124.05
2	118.36	126.16	72.97	71.77	99.37	99.28
3	95.21	101.48	58.69	57.73	79.92	79.86
4	103.87	110.72	64.03	62.99	87.2	87.13
5	87.35	93.1	53.85	52.97	73.33	73.27
6	80.45	85.74	49.59	48.78	67.53	67.48
7	22.34	23.82	13.77	13.55	18.76	18.74
8	70.35	74.99	43.37	42.66	59.06	59.01
9	122.43	130.49	75.47	74.24	102.78	102.69
10	109.29	116.49	67.37	66.27	91.75	91.68
11	138.68	147.82	85.49	84.09	116.42	116.32
12	54.58	58.17	33.64	33.09	45.82	45.78
13	156.01	166.29	96.18	94.6	130.97	130.87
14	186.96	202.09	116.88	114.97	159.17	159.04
15	216.42	230.67	133.41	131.23	181.68	181.53

Table 6.38 Fuel cost per ton for departmental vehicles (N Transfer Station)

Br.	Cost/ton for DD1 vehicle	Cost/ton for DD2 vehicle	Cost/ton for DD3 vehicle	Cost/ton for DD4 vehicle	Cost/ton for DD5 vehicle	Cost/ton for DD6 vehicle
1	28.98	30.89	17.87	17.57	24.33	24.3
2	60.94	64.96	37.57	36.96	51.16	51.12
3	96.29	102.63	59.36	58.39	80.83	80.76
4	81.66	87.04	50.34	39.15	68.56	68.5
5	99.4	105.95	61.28	60.28	83.45	83.38
6	122.97	131.07	75.8	74.57	103.23	103.15
7	153.3	163.4	94.51	92.96	128.7	128.59
8	174.7	186.21	107.69	105.94	146.66	146.54
9	194.2	206.99	119.72	117.76	163.03	162.9
10	227.11	242.07	140.0	137.72	190.66	190.5
11	263.68	281.05	162.55	159.89	221.35	221.18
12	226.03	240.92	139.33	137.06	189.75	189.6
13	258.26	275.28	159.2	156.6	216.8	216.64
14	269.23	286.97	165.97	163.25	226.01	225.84
15	274.24	292.31	169.06	166.29	230.22	230.04

Table 6.39 Fuel cost per ton for departmental vehicles (S Transfer Station)

Br.	Cost/ton for DD1 vehicle	Cost/ton for DD2 vehicle	Cost/ton for DD3 vehicle	Cost/ton for DD4 vehicle	Cost/ton for DD5 vehicle	Cost/ton for DD6 vehicle
1	249.05	265.46	153.53	151.02	209.07	208.91
2	214.65	228.8	132.32	130.16	180.2	180.06
3	227.11	242.07	140.0	137.72	190.66	190.5
4	196.27	209.16	120.97	118.99	164.74	164.6
5	178.36	190.11	109.95	108.16	149.73	147.61
6	167.12	178.13	103.02	101.34	140.29	140.18
7	166.72	177.7	102.77	101.09	139.95	139.84
8	108.75	155.9	67.04	65.94	91.29	91.22
9	121.8	129.83	75.08	73.86	102.25	102.17
10	83.5	88.99	51.47	50.62	70.09	54.47
11	64.95	69.23	40.04	39.38	54.52	54.48
12	151.55	161.53	93.42	91.9	127.21	127.12
13	47.94	51.1	29.55	29.07	40.25	40.21
14	92.77	98.88	57.19	56.25	77.87	77.81
15	220.75	235.29	136.08	133.86	185.31	185.17

Table 6.40 Mileage calculation for TATA LPT 2518 Heavy Duty Trucks

Vehicle type	Remarks
25 MT TATA LPT 2518 Heavy Duty Trucks	Loaded : 5.5 km/l Unloaded: 7km/l

Table 6.41 Cost of fuel calculation for TATA LPT 2518 Heavy Duty Trucks

Deptt. vehicle	Avg. (MT)	Fuel Charge (Variable Cost) Rs./Km.*	
		Loaded (Rs./Km)	Unloaded (Rs./Km)
25 MT TATA LPT 2518 Heavy Duty Trucks	20 (payload)	Rs. 56.85 / 5.5 km = 10.33	Rs. 56.85 / 7 km = 8.12

**Diesel cost Rs. 56.85/ltr.*

Table 6.42 Per MT transportation cost of waste for TATA LPT 2518 Heavy Duty Trucks

Transfer Station to disposal site	Fuel charge (Rs/km)		Distance (Km)	Cost (Rs)	Cost/ton (Rs)
	Loaded (Rs/Km)	Unloaded (Rs/Km)			
East	10.33	8.12	13.049	240.75	12.04
North	10.33	8.12	21.524	397.121	19.87
South	10.33	8.12	8.72	60.884	8.442

(b) Fixed cost for departmental vehicles

Fixed running cost for departmental vehicles DD1, DD2, DD3, DD4, DD5 and DD6 are calculated on the basis of depreciation (assuming scrap value 10% of capital cost, life of vehicle as 10 years), interest (10% on reducing loan), wages of driver and helper [Basic, Dearness Allowances (D.A.), House Rent Allowances (H.R.A), Medical Allowances (M.A) including 30% overtime allowances)], wages of garage staff including managerial and administration, annual operational and maintenance costs (10% of capital cost). For the calculation of fixed idle cost, wages of driver and helper are not considered, as optimised numbers of drivers and helpers are available which is almost used regularly by the running vehicles (Paul K. et al. 2017). Different types of number of running and idle vehicles and their fixed and idle costs are shown in Table 5.46 below.

Fixed costs for TATA LPT 2518 Heavy Duty trucks have been calculated in the same manner as done for the local departmental vehicles, shown in Table 6.43

Table 6.43 Summary of number of running and idle departmental vehicles per day and fixed running cost and fixed idle cost per day for different vehicles

Type of vehicles	Total no. of vehicles	Vehicles in operation	Idle vehicle	Fixed cost for each running vehicle / day in Rs	Fixed cost for each idle vehicle /day in Rs
DD1	16	9(56.25%)	7	5291.27	3367.98
DD2	73	34(46.57%)	39	5568.25	3644.96
DD3	28	12(42.85%)	16	8097.28	5404.68
DD4	54	42(77.78%)	12	10484.52	6798.56
DD5	64	51(79.69%)	13	6329.9	4406.6
DD6	4	3(75%)	1	5775.9	3852.7
25 MT TATA LPT 2518 Heavy Duty Trucks				6199.08	3508.13

6.3.1.6.2 Cost of transportation for hired vehicles

Since hired vehicles carry garbage and silt/rubbish separately therefore, transportation cost (Rs / MT) for hired vehicles are considered for silt/rubbish and garbage separately for different zones and shown in Table 6.44, Table 6.48, Table 6.46 respectively for East, North and South transfer station.

Table 6.44 Transportation cost of garbage and silt (East Transfer Station) by hired Vehicles

Borough	Distance from Br centre to landfill site (KM)	Cost of garbage transportation by hired vehicles (Rs / MT)	Cost of silt transportation by hired vehicles (Rs / MT)
1	10.92	277	260
2	8.74	277	260
3	7.03	243	225
4	7.67	243	225
5	6.45	243	225
6	5.94	243	225
7	1.65	243	225
8	5.195	243	225
9	9.04	277	260
10	8.07	243	225
11	10.24	277	260
12	4.03	243	225
13	11.52	277	260
14	14.00	277	260
15	15.98	277	260

Zone wise variation of rate for silt & garbage

Zone	Rate of garbage (Rs / MT)	Rate of silt (Rs / MT)	Distance from Br central point to zone border
1	243.0	225.0	< 8.50 Km.
2	277.0	260.0	>=8.50 Km.

Table 6.45 Transportation cost of garbage and silt (North Transfer Station) by hired Vehicles

Borough	**Distance from Br centre to landfill site (KM)**	**Cost of garbage transportation by hired vehicles (Rs / MT)**	**Cost of silt transportation by hired vehicles (Rs / MT)**
1	2.14	390	360
2	4.50	390	360
3	7.11	390	360
4	6.03	390	360
5	7.34	390	360
6	9.08	390	360
7	11.32	390	360
8	12.9	468	434
9	14.34	468	434
10	16.77	468	434
11	19.47	468	434
12	16.09	468	434
13	19.07	468	434
14	19.88	468	434
15	20.25	468	434

Zone wise variation of rate for silt & garbage

Zone	**Rate of garbage (Rs / MT)**	**Rate of silt (Rs / MT)**	**Distance from Br central point to transfer station**
1	390.0	360.0	<12.0 Km.
2	468.0	434.0	>=12.0 Km.

Table 6.46 Transportation cost of garbage and silt (South Transfer Station) by hired Vehicles

Borough	**Distance from Br centre to landfill site (KM)**	**Cost of garbage transportation by hired vehicles (Rs / MT)**	**Cost of silt transportation by hired vehicles (Rs / MT)**
1	18.39	468	434
2	15.85	468	434
3	16.77	468	434
4	14.49	468	434
5	13.17	468	434
6	12.34	468	434
7	12.31	468	434
8	8.03	390	360
9	8.994	390	360
10	6.165	390	360
11	4.796	390	360
12	11.19	390	360
13	3.54	390	360
14	6.85	390	360
15	16.3	468	434

Zone wise variation of rate for silt & garbage

Zone	**Rate of garbage (Rs / MT)**	**Rate of silt (Rs / MT)**	**Distance from Br central point to transfer station**
1	390	360	<12.0 Km.
2	468	434	>=12.0 Km.

6.3.1.7 Results and discussions

In the case of transfer station near/inside KMC boundary, it is decided that each Heavy Duty truck will have to operate maximum 4 trips at East, 3 trips at North and 5 trips at South. The total number of such trucks operating is the input data, while the program is free to choose the number of trucks required in the East, North and South direction — so as to optimise the total cost for a particular input of total number of trucks. Operation and maintenance cost of composting and incineration includes the loading charge of process reject and inert waste to the TATA LPT Heavy Duty trucks for transportation from transfer station to landfill site. Table A-6.4 of Annexure 6.4 shows part of the input data fed into LINGO for this section. Various runs were executed with different total number of trucks (however total trucks: running trucks ratio was kept constant) and the results are tabulated below:

Table 6.47 Table showing results of different runs with different total-running-idle heavy duty truck Combinations

total-running-idle	S.W.M. cost (Rs)	SGF(E) in MT	SGF(N) in MT	SGF(S) in MT
14-9-5	No feasible solution			
16-11-5	18,50,332	0	0	2864.707
18-12-6	17,13,456	1480.795	0	1383.912
21-14-7	**16,39,421**	**1519.926**	**444.2385**	**900.5427**
24-16-8	16,54,459	1459.480	504.6840	900.5427

Table 6.47 thus shows that the total cost is optimised when total number of Heavy Duty trucks is 21. An examination of the output results reveals that out of the 14 running trucks, 9 trucks are running in the East because distance of East landfill site is lesser than other two landfill site from borough centre, while 2 trucks are running in the North and 3 in the South direction.

The LINGO program developed for this particular run is shown in Annexure 6.6 while the mathematical equations generated by LINGO from the program are given in Annexure 6.7. A summary of the costs of different variables for 21-14-7 combination is given below in Table 6.48. A details summary of input data use for this run is given in Annexure 6.4. A detailed summary of results is given in Table 6.49, Table 6.50 and Table 6.51.

Table 6.48 Output summary for transfer station at near with total 21 Heavy Duty Trucks

Item	Cost (Rs/day)
Total SWM Cost (Obj. value)	**16,39,421.00**
Total transportation cost (CTRANSP)	**19,48,341.00**
Incentive cost (CINCT)	**7,014.17**
Land filling cost (CTCX)	**2,13,672.40**
Sorting cost (CTCS)	2,92,500.90
Incineration cost (CTCI)	**3,33,138.90**
Composting cost (CTCC)	**5,29,130.40**
Revenue earned from recyclables (CTREVR)	47,000.69
Revenue earned from composting (CTREVC)	13,01,952.00
Revenue earned from incineration (CTREVI)	3,35,424.30

Here, 53.05%, 15.51%and 31.43% of disposable waste enters East, North and South landfills respectively. Because of East landfill is nearest among three of the landfill.

Table 6.49 Analysis of waste (silt & garbage) transported by departmental and hired vehicles

	WASTE TRANSPORTED BY VEHICLES IN MT								
BR.	**DD1**	**DD2**	**DD3**	**DD4**	**DD5**	**DD6**	**HH (SILT+ GARBAGE)**	**Borough wise total for dept. vehicle**	**HH (GARBAGE)**
BR 1	0	27.479	25.516	53.7807	69.87568	0	40.738	176.652	19.628
BR 2	0	23.116	13.484	63.5679	73.1994	0	31.893	173.367	19.263
BR 3	0	17.769	19.743	61.2033	82.9206	0	36.8844	181.6356	15.794
BR 4	0	3.437	20.966	56.7105	73.5518	0	30.535	154.665	17.185
BR 5	0	0	28.197	72.1508	86.24928	0	38.733	186.597	20.733
BR 6	0	0	25.764	94.8115	116.4533	0	57.5112	237.028	20.6112
BR 7	0	31.88	18.597	85.0144	106.268	0	89.6103	241.7597	23.9103
BR 8	0	11.311	17.643	60.6919	74.43401	0	54.4301	164.0799	12.3501
BR 9	0	8.778	26.334	98.8988	129.3292	0	56.46	263.34	29.26
BR 10	0	12.23	0	132.308	189.0111	0	69.561	333.549	37.061
BR 11	13.65	0	9.45	23.1	0	17.85	42.84	64.05	40.95
BR 12	11.027	0	9.189	19.2969	36.756	13.784	4.1978	90.052	1.8378
BR 13	17.275	0	20.73	31.095	39.7325	22.458	45.6	131.29	41.46
BR 14	5.6879	0	17.064	27.0174	36.97122	21.33	43.96728	108.069	34.127
BR 15	0	0	0.244	0	0	0	24.216	0.244	24.156
TOTAL	**47.64**	**136**	**252.92**	**879.647**	**1114.752**	**75.421**	**667.17708**	**2506.379**	**358.327**

Table 6.50 Waste transported to different transfer stations/disposal sites and undergoing different processes

DUMPSITES /TRANSFER STATIONS	**TOTAL WASTE (GARBAGE+SILT) TO DUMPSITE/ TRANSFER STATION (MT)**	**SORTER FEED (MT)**	**INCINERATOR FEED (MT)**	**COMPOSTING PLANT FEED (MT)**	**LANDFILL QUANTITY (MT)**
EAST	1828.776	1519.926	255.9555	1039.933	719.4202
NORTH	444.2385	444.2385	74.80977	303.948	120
SOUTH	900.5427	900.5427	151.6514	616.1513	243.2592

Table 6.51 Break-up of waste transportation cost and incentive cost by different departmental and hired vehicles

	VEHICLE TYPES							
	DD1	**DD2**	**DD3**	**DD4**	**DD5**	**DD6**	**HH (silt+garbage)**	**Trucks**
FUEL COST (Rs)	2844.24	8288.35	11567.6	39209.86	71063	4166.15	0	23965.1
FIXED RUNNING COST (Rs)	47621.4	189321	97167.36	440349.8	322825	17327.7	0	86787.1
FIXED IDLE COST (Rs)	23575.9	142153	86474.88	81582.72	57285.8	3852.7	0	24556.9
TOTAL TRANSPORTATION COST (Rs)	74041.5	339762	195209.8	561142.4	451174	25346.5	166355.9	135309
INCENTIVE COST (Rs)	484.19	0	1273.81	2720.234	1610.79	925.149	0	0

Quantity of waste transported by individual vehicle types from different boroughs to the transfer stations/disposal sites is depicted in Figure 6.11.

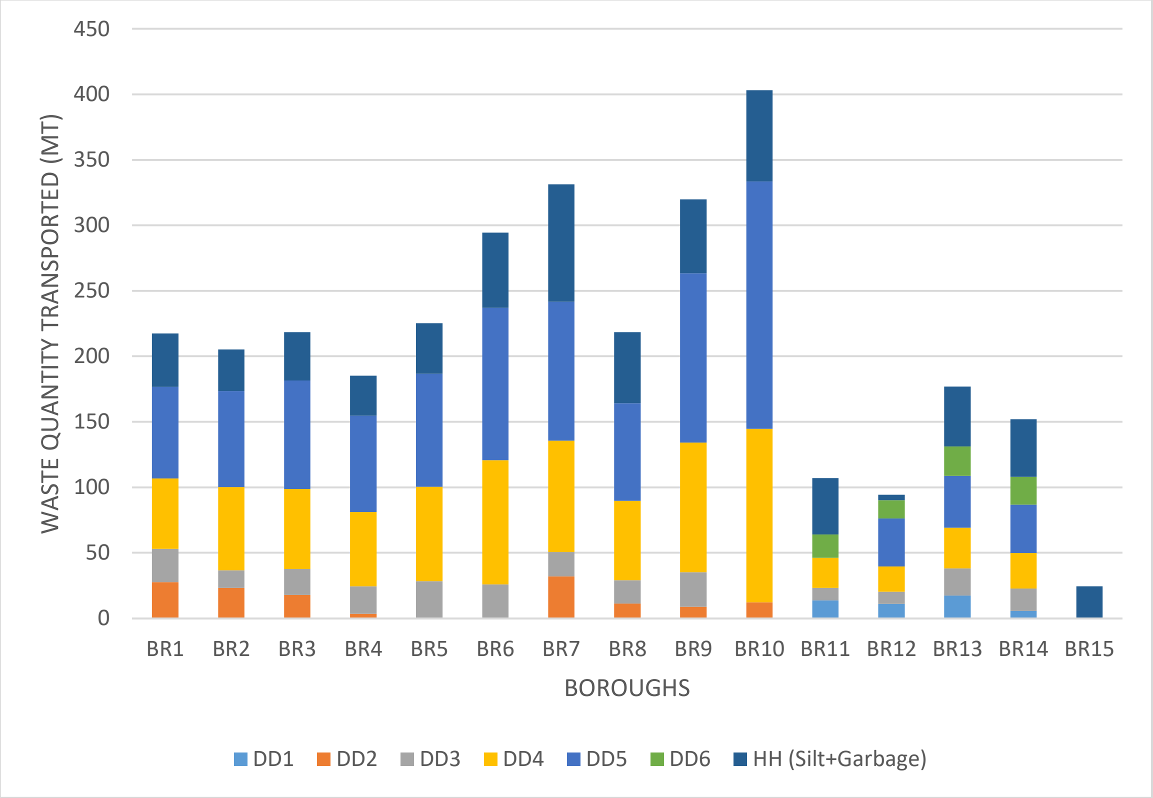

Figure 6.11 Quantity of waste transported by different vehicle types from different boroughs (transfer station near/within KMC boundary)

Figure 6.11 and Table 6.49 reveals that DD1, DD2, DD3, DD4, DD5, DD6, HH transfers 1.66%, 4.75%, 8.83%, 30.7%, 38.9%, 2.63%, 12.5% of garbage respectively. DD5 takes highest amount of garbage, since its number of vehicles is high (Table 6.43) and maximum garbage carrying range is also high (Table 6.33), while the hired vehicles transport waste as per their minimum garbage carrying range.

The results of waste quantity (garbage + silt) transported to different transfer station/disposal sites and subjected to different processing techniques (garbage) is shown in Figure 6.12.

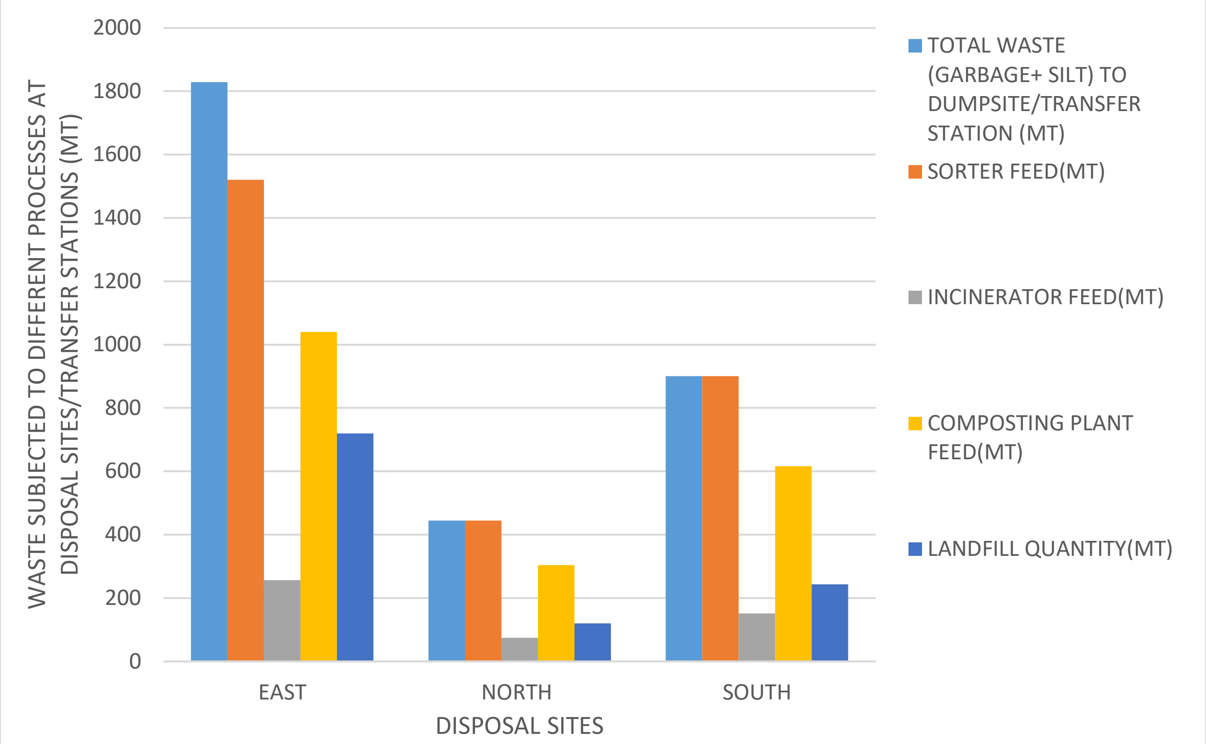

Figure 6.12 Waste quantity entering different transfer stations/disposal sites and processing plants (transfer station near/within KMC boundary)

Figure 6.12 and Table 6.50 illustrates that 57.62% of waste has entered East transfer station, while 13.99% and 28.3% of waste has entered North and South transfer station respectively. Garbage from boroughs 1 and 2 have been transferred to North transfer station since distance of these borough centres to North transfer station is the least (Table 6.31); garbage from boroughs 3, 5, 6, 7, 8, 12 have been transported to the East since East transfer station is nearest, while garbage from boroughs 9, 10, 11, 13, 14 have been transported to their nearest South transfer station. Garbage from borough 4 has been transported to both East and North.

Figure 6.13 shows transportation cost and incentive cost incurred by different departmental and hired vehicle.

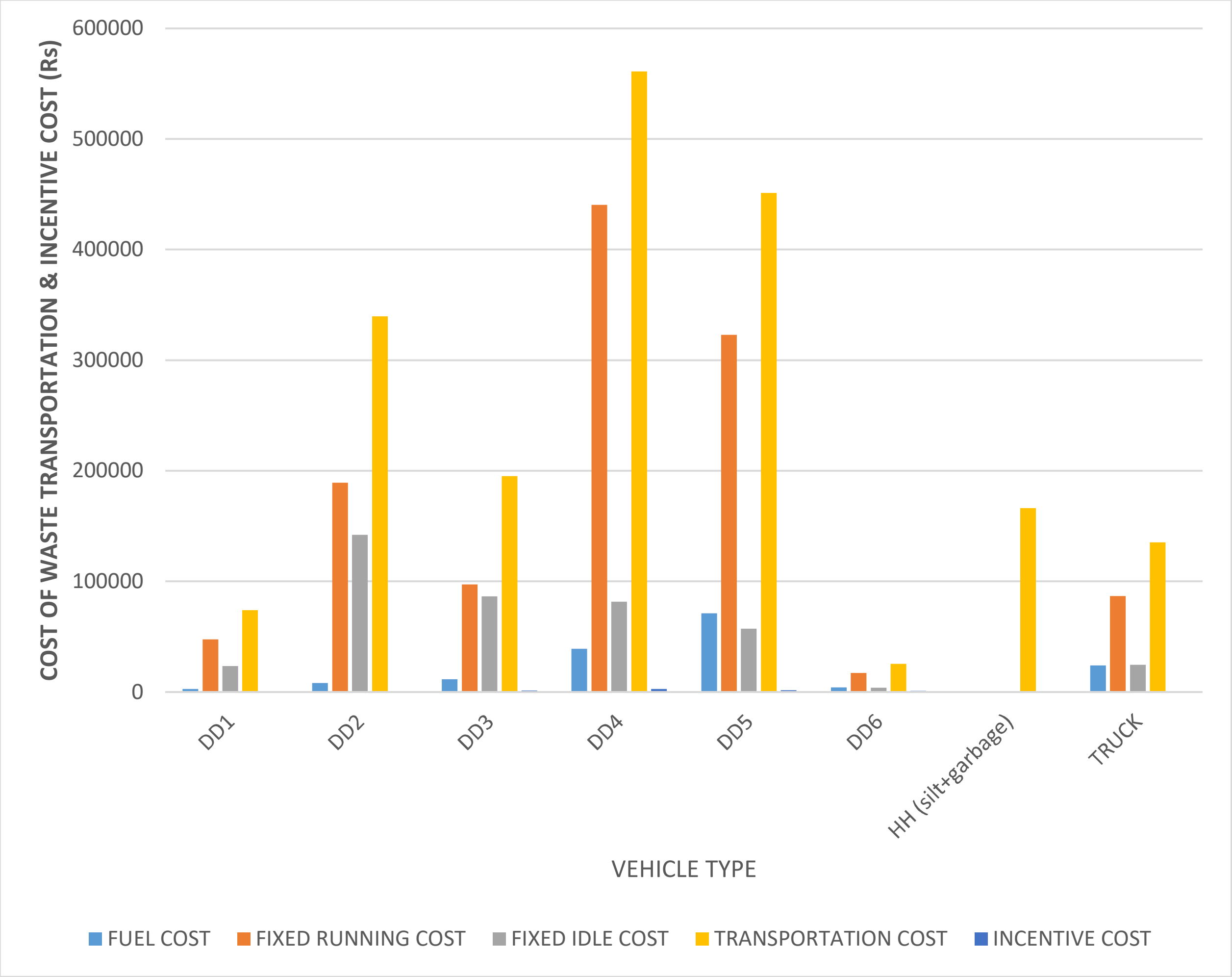

Figure 6.13 Figure showing transportation cost and incentive cost for different vehicle types (transfer station near/within KMC boundary)

In this case, both DD4 and DD3 transport garbage as per their maximum garbage carrying range (Table 6.14), except for borough 1 and borough 7. For these two boroughs, DD4 does not collect garbage as per its maximum range — DD2 takes up the balance amount for these two boroughs. This is because, although the per MT garbage transportation fuel cost is high for DD2, yet, no incentive is to be paid for transportation by DD2, while extra incentive needs to be paid for transporting by DD4 [LINGO output shows CINC (DD2) = 0; refer Table 6.51] and for these two boroughs DD4 (transportation fuel cost + incentive cost) is higher than DD2 transportation fuel cost.

Table 6.49, Table 6.51 and Figure 6.13shows that although DD4 and DD5 transport 30.7% and 38.9% of garbage respectively, yet total transportation cost of DD4 (Rs.5,61,142.38) is more than DD5 (Rs.4,51,173.74). This is because fixed cost of vehicles is the highest for DD4.

We have run a integrated solid waste management model (Run 1) with considering incineration, composting plant, 3 nos. of transfer station and 3 nos. of landfills along East, North, and South direction. It is our proposed situation, and result come out from the model is the total SWM cost will be Rs. 16,39,421.00 per day, a total of 57.62% of waste has entered East landfill, while 13.99% and 28.3% of waste has entered North and South landfill respectively. From these results it is evident that the construction of East landfill site should be the first priority.

As because it is a proposed case, so if we construct 3 nos. of transfer station and 3 nos. of landfill then we can manage our generated solid waste in a proper manner with minimizing the total cost of SWM. But in practical situation land acquisition and economy is main reason for our proposed model. So we may not construct all transfer station and landfill site at the same time. We have to construct transfer station along with landfill one by one or any two at a time. For that purpose we do not know which two transfer stations and landfill sites have to construct first for minimizing the cost. Installation of transfer station and making the landfill are time taking process, and during that period we may have to deposit the waste in the finished sites. Besides in any accidental condition (say technical fault in the bio/thermal processing units, garbage dump landslide, public agitation against accidental spills etc.) one landfill may not be used for depositing purpose. For these cases we have to know the operational change and capacity increment of the other landfill along with their cost implications. If a landfill is most important for minimisation of cost then we should have to fix that problem as soon as possible.

We have run the model with 3 nos. of combination. In first combination (Run 2) we have considered East landfill site along with transfer station is not in working condition but other two are in working condition. In second combination (Run 3) we have considered North landfill site along with transfer station is not in working condition but other two are in working condition. In third combination (Run 4) we have considered South landfill site along with transfer station is not in working condition but other two are in working condition.

RUN 2:

6.3.2 Transfer stations located near KMC boundary without considering East transfer station and East landfill site

We have considered here that, only North and South transfer stations along with landfill sites. North and South transfer station are same as Run 1 of sub chapter 6.3.1. The conditions and all other constraints are given below. We want to see the variation of total cost and other cost of the solid waste management.

6.3.2.1 Borough-Zones associated with transfer station/disposal sites

Same as Table 6.31, Table 6.32 of sub chapter 6.3.1.1

6.3.2.2 Borough-wise garbage and silt/rubbish generation

Same as Table 6.13, of sub chapter 6.1.10

6.3.2.3 Types of vehicles for transportation of waste

Same as sub chapter 6.1.11

6.3.2.4 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Same as Table 6.14 of sub chapter 6.1.12

6.3.2.5 Maximum and minimum trip limits for departmental vehicles

Same as Table 6.15 of sub chapter 6.1.13

6.3.2.6 Transportation cost

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the transfer station. Additionally, cost of transporting dumpable waste from transfer station to disposal site (landfill site) needs to be considered.

6.3.2.6.1 Cost of transportation for departmental vehicles

(a) Fuel Cost
Same as Table 6.33, Table 6.35, Table 6.36, Table 6.38, Table 6.39, Table 6.40, Table 6.41, Table 6.42(only North and South) of sub chapter 6.3.1.6.1

(b) Fixed cost for departmental vehicles
Same as Table 6.43

6.3.2.6.2 Cost of transportation for hired vehicles

Same as Table 6.45, Table 6.46 of sub chapter 6.3.1.6.2.

6.3.2.7 Results and discussions

In the case of transfer station near/inside KMC boundary, it is decided that each Heavy Duty truck will have to operate maximum 3 trips at North and 5 trips at South. The total number of such trucks operating is the input data, while the program is free to choose the number of trucks required in the North and South direction — so as to optimise the total cost for a particular input of total number of trucks. Various runs were executed with different total number of trucks (however total trucks: running trucks ratio was kept constant) and the results are tabulated below:

Table 6.52 Table showing results of different runs with different total-running-idle truck Combinations

total-running-idle	S.W.M. cost (Rs/day)	SGF(E) in MT/day	SGF(N) in MT/day	SGF(S) in MT/day
15-10-5	No feasible solution			
16-11-5	18,50,332.00	-	0	2864.707
18-12-6	18,03,440.00	-	444.2385	2420.468
21-14-7	**17,73,316.00**	**-**	**1247.070**	**1617.637**
24-16-8	17,84,238.00	-	1377.249	1487.458

Table 6.52 thus shows that the total cost is optimised when total number of Heavy Duty trucks is 21. An examination of the output results reveals that out of the 14 running trucks, 7 trucks are running in the North and 7 in the South direction.

A summary of the costs of different variables for 21-14-7 combination is given below in Table 6.53.

A details summary of input data use for this run is given in Table A-6.4 of Annexure 6.4 without considering East Landfill site. A detailed summary of results is given in Table 6.54, Table 6.55 and Table 6.56.

Table 6.53 Output summary for transfer station near without considering East transfer station and East landfill site with total 21 Heavy Duty Trucks

Item	Cost (Rs/day)
Total SWM Cost (Obj. value)	17,73,316.00
Total transportation cost (CTRANSP)	20,81,848.00
Incentive cost (CINCT)	7,054.019
Land filling cost (CTCX)	2,14,020.3
Sorting cost (CTCS)	2,92,500.9
Incineration cost (CTCI)	3,33,138.9
Composting cost (CTCC)	5,29,130.4
Revenue earned from recyclables (CTREVR)	47,000.69
Revenue earned from composting (CTREVC)	13,01,952.00
Revenue earned from incineration (CTREVI)	3,35,424.30

Here, 43.53% and 56.47% of disposable waste enters North and South landfills respectively. Because both landfill are nearly same distance from borough centre. But in Run 1, 13.99% of waste and 28.3% of waste are going to North and South dumpsite. The SWM cost here is 8.17% more than Run 1 and transportation cost is 6.85% more than Run 1, because in Run 1 all transfer stations and landfill sites have considered but here we have not considered East transfer station along with East landfill site, so more number of trips are required for transferring the waste in other two landfill sites.

Table 6.54 Waste transported to different transfer stations/disposal sites and undergoing different processes

DUMPSITES/ TRANSFER STATIONS	TOTAL WASTE (GARBAGE+ SILT) TO DUMPSITE/ TRANSFER STATION (MT)	SORTER FEED (MT)	INCINERATOR FEED (MT)	COMPOSTING PLANT FEED (MT)	LANDFILL QUANTITY (MT)
NORTH	1330.20496	1247.07	210.0066	853.2455	420
SOUTH	1843.352	1617.637	272.41	1106.787	662.6794

Table 6.55 Break-up of waste transportation cost and incentive cost by different departmental and hired vehicles

VEHICLE TYPES	FUEL COST (Rs)	FIXED RUNNING COST (Rs)	FIXED IDLE COST (Rs)	TOTAL TRANSPORTATION COST (Rs)	INCENTIVE COST (Rs)
DD1	3913.397	47621.43	23575.86	75110.69	484.1904
DD2	11186.68	189320.5	142153.4	342660.6	0
DD3	14800.36	97167.36	86474.88	198442.6	1273.809
DD4	53018.49	440349.8	81582.72	574951	2895.576
DD5	94548.23	322824.9	57285.8	474658.9	1475.293
DD6	5287.295	17327.7	3852.7	26467.69	925.1494
HH (silt+garbage)	0	0	0	260639.9	0
TRUCKS	17572.74	86787.12	24556.91	128916.8	0

Table 6.56 Analysis of waste (silt & garbage) transported by departmental and hired vehicles

BR.	DD1	DD2	DD3	DD4	DD5	DD6	HH (Silt + Garbage)	Borough wise total Dept. vehicle	HH (Garbage)
1	0	27.479	25.516	53.781	69.8757	0	40.738	176.652	19.628
2	0	23.116	13.484	63.568	73.1994	0	31.893	173.367	19.263
3	0	17.769	19.743	61.203	82.9206	0	36.8844	181.636	15.7944
4	0	13.404	20.966	56.711	63.5845	0	30.535	154.665	17.185
5	0	0	28.197	72.151	86.2493	0	38.733	186.597	20.733
6	0	0	25.764	94.812	116.453	0	57.5112	237.029	20.6112
7	0	5.3134	18.597	92.985	124.865	0	89.6103	241.76	23.9103
8	0	7.0572	17.643	60.692	78.6878	0	54.4301	164.08	12.3501
9	0	8.778	26.334	98.899	129.329	0	56.46	263.34	29.26
10	0	33.084	0	132.31	168.158	0	69.561	333.549	37.061
11	13.65	0	9.45	23.1	0	17.85	42.84	64.05	40.95
12	11.027	0	9.189	19.297	36.756	13.78	4.1978	90.0522	1.8378
13	17.275	0	20.73	31.095	39.7325	22.46	45.6	131.29	41.46
14	5.6879	0	17.064	27.017	36.9712	21.33	43.96728	108.07	34.12728
15	0	0	0.244	0	0	0	24.216	0.244	24.156
TOTAL	**47.64**	**136**	**252.92**	**887.62**	**1106.78**	**75.42**	**667.1771**	**2506.38**	**358.3271**

Quantity of waste transported by individual vehicle types from different boroughs to the transfer stations/disposal sites is depicted in Figure 6.14.

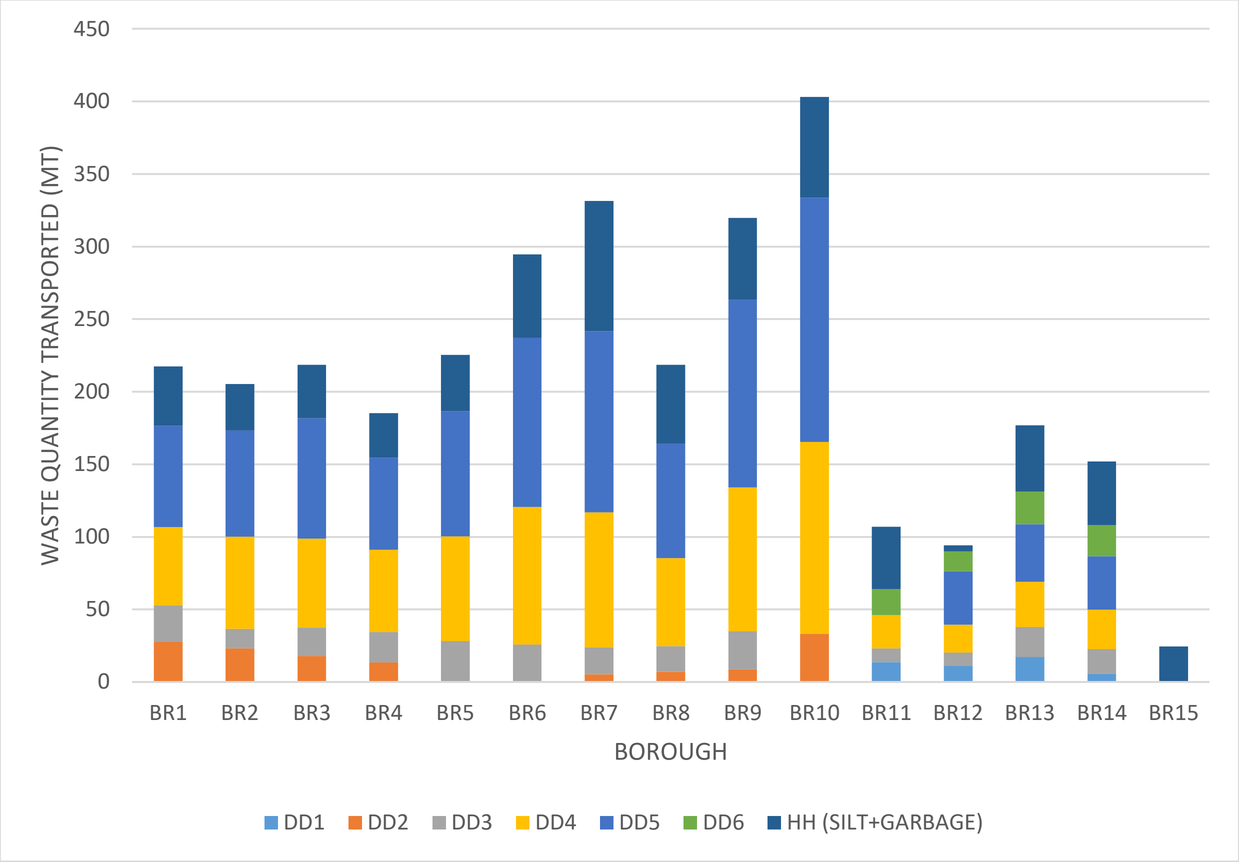

Figure 6.14 Quantity of waste transported by different vehicle types from different boroughs (Run 2)

Figure 6.14 and Table 6.56 reveals that DD1, DD2, DD3, DD4, DD5, DD6, HH transfers 1.5%, 4.3%, 7.97%, 27.97%, 34.88%, 2.4%, 21.04% of garbage respectively. DD5 takes highest amount of garbage, since its number of vehicles is high (Table 6.43) and maximum garbage carrying range is also high (Table 6.33), while the hired vehicles transport waste as per their minimum garbage carrying range. These results are almost similar to that obtained when transfer station was at near between borough centres and disposal sites with three landfill sites are in working condition.

The results of waste quantity (garbage + silt) transported to different transfer station/disposal sites and subjected to different processing techniques (garbage) is shown in Figure 6.15.

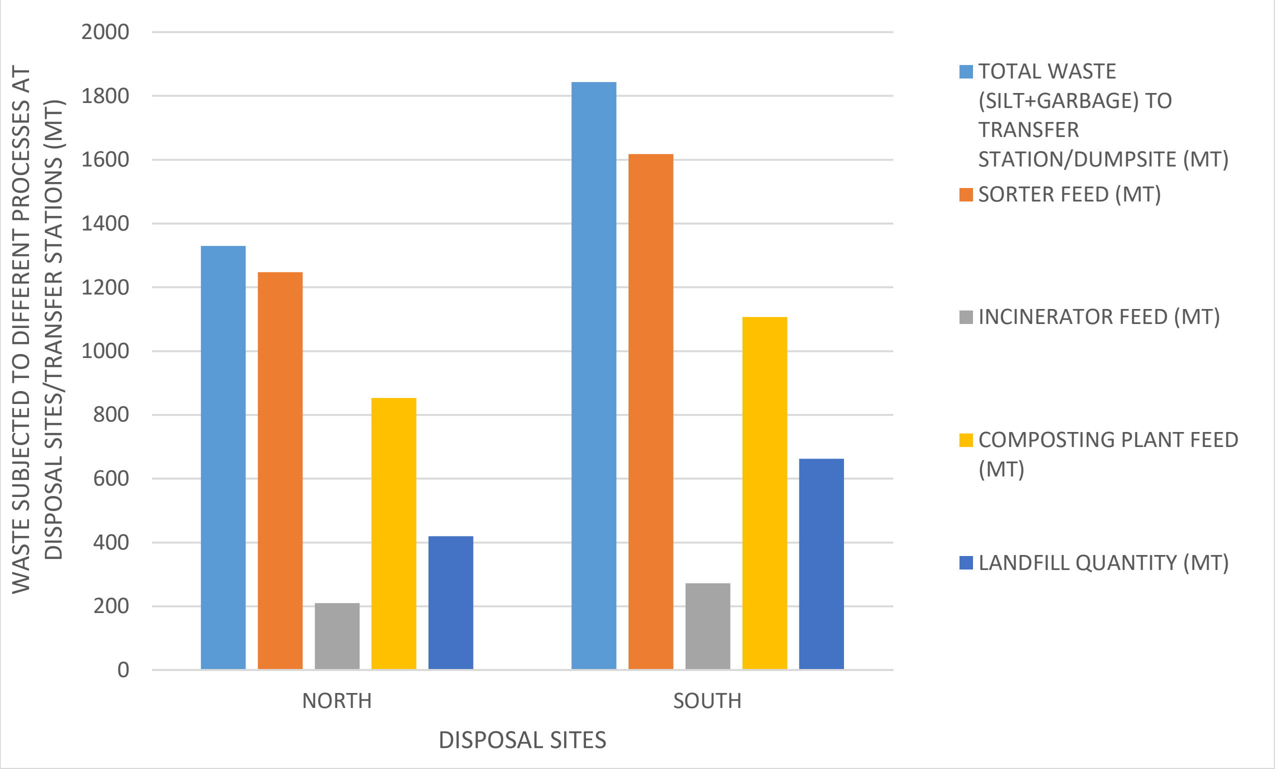

Figure 6.15 Waste quantity entering different transfer stations/disposal sites and processing plants (Run 2)

Figure 6.15 and Table 6.54 illustrates that 43.53% of waste has entered North transfer station, and 56.47% of waste has entered South transfer station respectively. Whereas in Run 1, 13.99% of waste and 28.3% of waste are going to North and South dumpsite. So when East Garbage from boroughs 1 to 6 have been transferred to North transfer station since distance of these borough centres to North transfer station is the least (Table 6.31); garbage from boroughs 8 to 15 have been transported to the South since South transfer station is nearest. Garbage from borough 7have been transported to both North and South transfer station.

Silt from borough 1 to 5 and borough 8 to 15 have been transported to South landfill, while silt from borough 7 has been transported to North landfill. Silt from borough 6 has been transported to both North and South landfill.

Figure 6.16 shows transportation cost and incentive cost incurred by different departmental and hired vehicle.

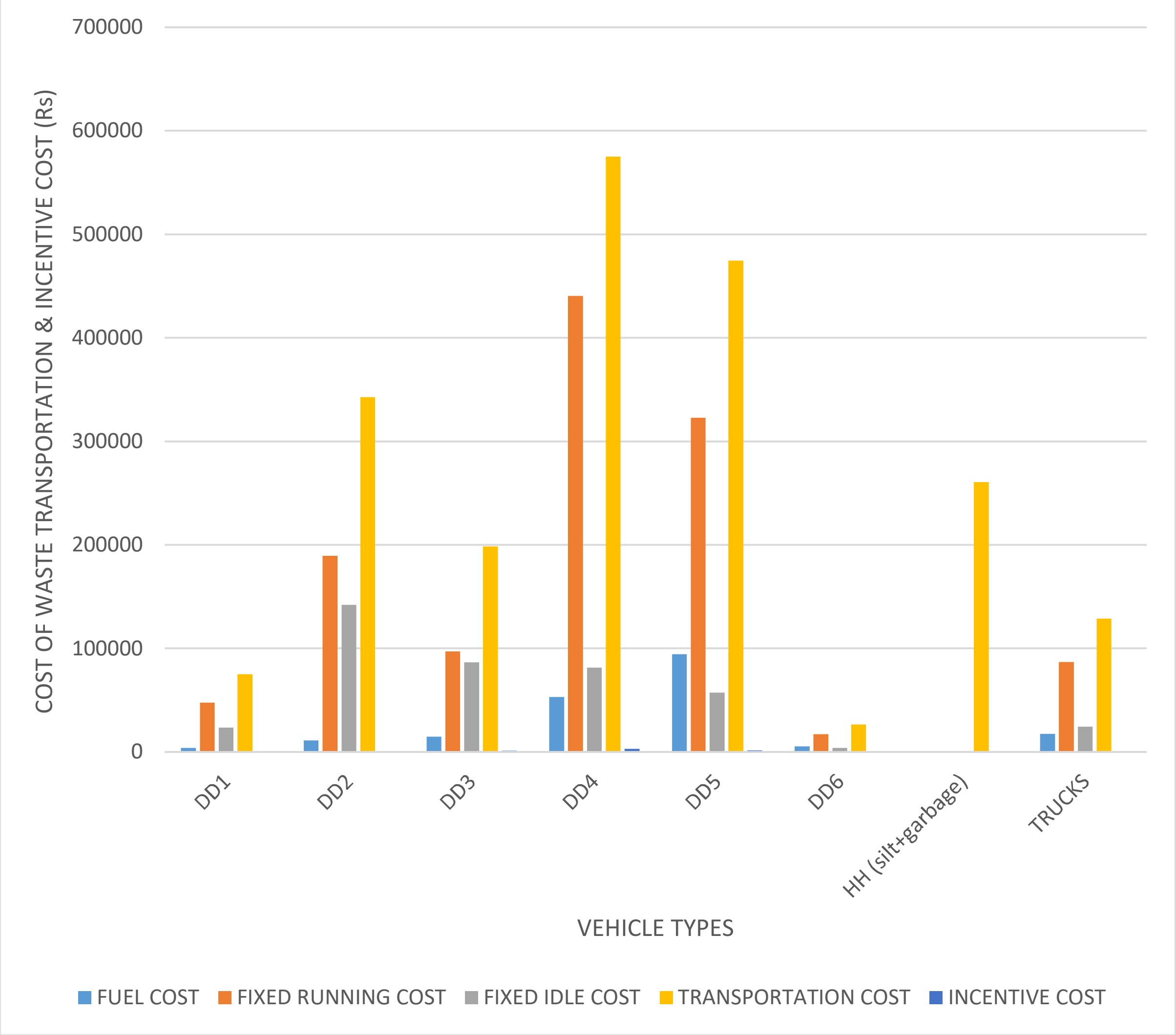

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Figure 6.16 Figure showing transportation cost and incentive cost for different vehicle types (Run 2)

In this case, both DD4 and DD3 transport garbage as per their maximum garbage carrying range (Table 6.14), except for borough 1 and borough 7. For these two boroughs, DD4 does not collect garbage as per its maximum range — DD2 takes up the balance amount for these two boroughs. This is because, although the per MT garbage transportation fuel cost is high for DD2, yet, no incentive is to be paid for transportation by DD2, while extra incentive needs to be paid for transporting by DD4 [LINGO output shows CINC (DD2) = 0; refer Table 6.55] and for these two boroughs DD4 (transportation fuel cost + incentive cost) is higher than DD2 transportation fuel cost.

Table 6.55, Table 6.56 and Figure 6.16 shows that although DD4 and DD5 transport 27.97% and 34.88% of garbage respectively, yet total transportation cost of DD4 (Rs. 574951) is more than DD5 (Rs. 474658.9). This is because fixed cost of vehicles is the highest for DD4.

RUN 3:

6.3.3 Transfer stations located near KMC boundary without considering North transfer station and North landfill site

We have considered here that, only East and South transfer stations along with landfill sites. East and South transfer station are same as Run 1 of sub chapter 6.3.1. The conditions and all other constraints are given below. We want to see the variation of total cost and other cost of the solid waste management.

6.3.3.1 Borough-Zones associated with transfer station/disposal sites

Same as Table 6.30, Table 6.32 of sub chapter 6.3.1.1

6.3.3.2 Borough-wise garbage and silt/rubbish generation

Same as Table 6.13, of sub chapter 6.1.10

6.3.3.3 Types of vehicles for transportation of waste

Same as sub chapter 6.1.11

6.3.3.4 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Same as Table 6.14 of sub chapter 6.1.12

6.3.3.5 Maximum and minimum trip limits for departmental vehicles

Same as Table 6.15 of sub chapter 6.1.13

6.3.3.6 Transportation cost

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the transfer station. Additionally, cost of transporting dumpable waste from transfer station to disposal site (landfill site) needs to be considered.

6.3.3.6.1 Cost of transportation for departmental vehicles

(a) Fuel Cost

Same as Table 6.33, Table 6.34, Table 6.36, Table 6.37, Table 6.39, Table 6.40, Table 6.41, Table 6.42 (only East and South) of sub chapter 6.3.1.6.1

(b) Fixed cost for departmental vehicles
Same as Table 6.43

6.3.3.6.2 Cost of transportation for hired vehicles

Same as Table 6.44, Table 6.46 of sub chapter 6.3.1.6.2.

6.3.3.7 Results and discussions

In the case of transfer station near/inside KMC boundary, it is decided that each Heavy Duty truck will have to operate maximum 4 trips at East and 5 trips at South. The total number of such trucks operating is the input data, while the program is free to choose the number of trucks required in the North and South direction — so as to optimise the total cost for a particular input of total number of trucks. Various runs were executed with different total number of trucks (however total trucks: running trucks ratio was kept constant) and the results are tabulated below:

Table 6.57 Table showing results of different runs with different total-running-idle heavy duty truck Combinations

total-running-idle	**S.W.M. cost (Rs)**	**SGF(E) in MT**	**SGF(N) in MT**	**SGF(S) in MT**
15-10-5	No feasible solution			
16-11-5	18,50,332.00	-	0	2864.707
20-13-7	**16,60,125.00**	**1885.829**	**-**	**978.8776**
21-14-7	16,63,502.00	1964.164	-	900.5427
24-16-8	16,79,409.00	1964.164	-	900.5427

Table 6.57 thus shows that the total cost is optimised when total number of Heavy Duty trucks is 20. An examination of the output results reveals that out of the 13 running trucks, 10 trucks are running in the East and 3 in the South direction.

A summary of the costs of different variables for 20-13-7 combination is given below in Table 6.58.

A details summary of input data use for this run is given in Table A-6.4 of Annexure 6.4 without considering North landfill site. A detailed summary of results is given in Table 6.59, Table 6.60 and Table 6.61.

Table 6.58 Output summary for transfer station near without considering North transfer station and North landfill site with total 20 Heavy Duty Trucks

Item	Cost (Rs/day)
Total SWM Cost (Obj. value)	16,60,125.00
Total transportation cost (CTRANSP)	19,69,951.00
Incentive cost (CINCT)	7,059.313
Landfilling cost (CTCX)	2,12,721.1
Sorting cost (CTCS)	2,92,500.9
Incineration cost (CTCI)	3,33,138.9
Composting cost (CTCC)	5,29,130.4
Revenue earned from recyclables (CTREVR)	47,000.69
Revenue earned from composting (CTREVC)	13,01,952.00
Revenue earned from incineration (CTREVI)	3,35,424.30

Here, 65.83% and 34.17% of disposable waste enters East and South landfills respectively. Because East landfill is lesser distance than South landfill from borough centre. But in Run 1, 57.71% of waste, 13.99% of waste and 28.3% of waste are going to East, North and South landfill. For Run 2, 43.53% and 56.47% of disposable waste enters North and South landfills respectively.

The table shows that without considering North landfill site, total SWM cost, transportation cost decreases by 6.38%, 5.37% respectively and incentive cost increase by 0.75% in comparison with Run 2, and also total SWM cost, transportation cost increased by 1.26%, 1.10% respectively in comparison with Run 1. The main reason of decreasing transportation cost is that, here 20 Heavy duty trucks are required while in Run 2 we used 21 Heavy duty trucks. Cost of landfilling, CTCX has decreased by 0.61% over Run 2 — this is because in Run 2, only 43.53% of disposable waste was entering North landfill site while 56.47% was entering South, but here, 65.83%and 34.17% of disposable waste enters East and South landfills respectively. Because operating cost of North landfill sites is slightly more than East, for that cost of landfilling is decreased over Run 2.

Table 6.59 Waste transported to different transfer stations/disposal sites and undergoing different processes

Dumpsites/ Transfer station	Total waste(silt+ garbage) to dumpsites /transfer station (MT)	Sorter feed (MT)	Incinerator feed (MT)	Composting plant feed (MT)	Landfill quantity (MT)
EAST	2176.419	1885.829	317.574	1290.284	800
SOUTH	997.136	978.877	164.843	669.748	282.679

Table 6.60 Break-up of waste transportation cost and incentive cost by different departmental and hired vehicles

Vehicle types	Fuel cost (Rs)	Fixed running cost (Rs)	Fixed idle cost(Rs)	Total transportation cost (Rs)	Incentive cost(Rs)
DD1	2844.24	47621.43	23575.86	74041.53	484.1904
DD2	11259.91	189320.5	142153.4	342733.8	0
DD3	14332.9	97167.36	86474.88	197975.1	1273.809
DD4	48875.39	440349.8	81582.72	570807.9	2918.87
DD5	82662.1	322824.9	57285.8	462772.8	1475.293
DD6	4166.15	17327.7	3852.7	25346.54	925.1494
HH (silt+garbage)	0	0	0	168181.9	0
TRUCKS	22946.38	80588.04	24556.91	128091.3	0

Table 6.61 Analysis of waste (silt & garbage) transported by departmental and hired vehicles

	WASTE TRANSPORTED BY VEHICLES IN MT								
BR.	**DD1**	**DD2**	**DD3**	**DD4**	**DD5**	**DD6**	**HH (Silt + Garbage)**	**Borough wise total Dept. vehicle**	**HH (Garbage)**
1	0	7.851	25.516	62.809	80.475	0	40.738	176.651	19.628
2	0	7.705	13.484	63.568	88.609	0	31.893	173.366	19.263
3	0	17.769	19.743	61.203	82.921	0	36.884	181.636	15.7944
4	0	3.437	20.966	56.711	73.552	0	30.535	154.665	17.185
5	0	0	28.197	72.151	86.249	0	38.733	186.597	20.733
6	0	2.576	25.764	94.812	113.87	0	57.511	237.029	20.6112
7	0	31.88	18.597	85.014	106.27	0	89.610	241.759	23.9103
8	0	16.937	17.643	60.692	68.807	0	54.430	164.079	12.3501
9	0	8.778	26.334	98.899	129.33	0	56.46	263.34	29.26
10	0	39.066	0	132.31	162.17	0	69.561	333.549	37.061
11	13.65	0	9.45	23.1	0	17.85	42.84	64.05	40.95
12	11.027	0	9.189	19.297	36.756	13.78	4.1978	90.0522	1.8378
13	17.275	0	20.73	31.095	39.732	22.46	45.6	131.29	41.46
14	5.688	0	17.064	27.017	36.971	21.33	43.967	108.07	34.12728
15	0	0	0.244	0	0	0	24.216	0.244	24.156
Total	**47.64**	**136**	**252.92**	**888.68**	**1105.72**	**75.42**	**667.18**	**2506.38**	**358.3271**

Quantity of waste transported by individual vehicle types from different boroughs to the transfer stations/disposal sites is depicted in Figure 6.13.

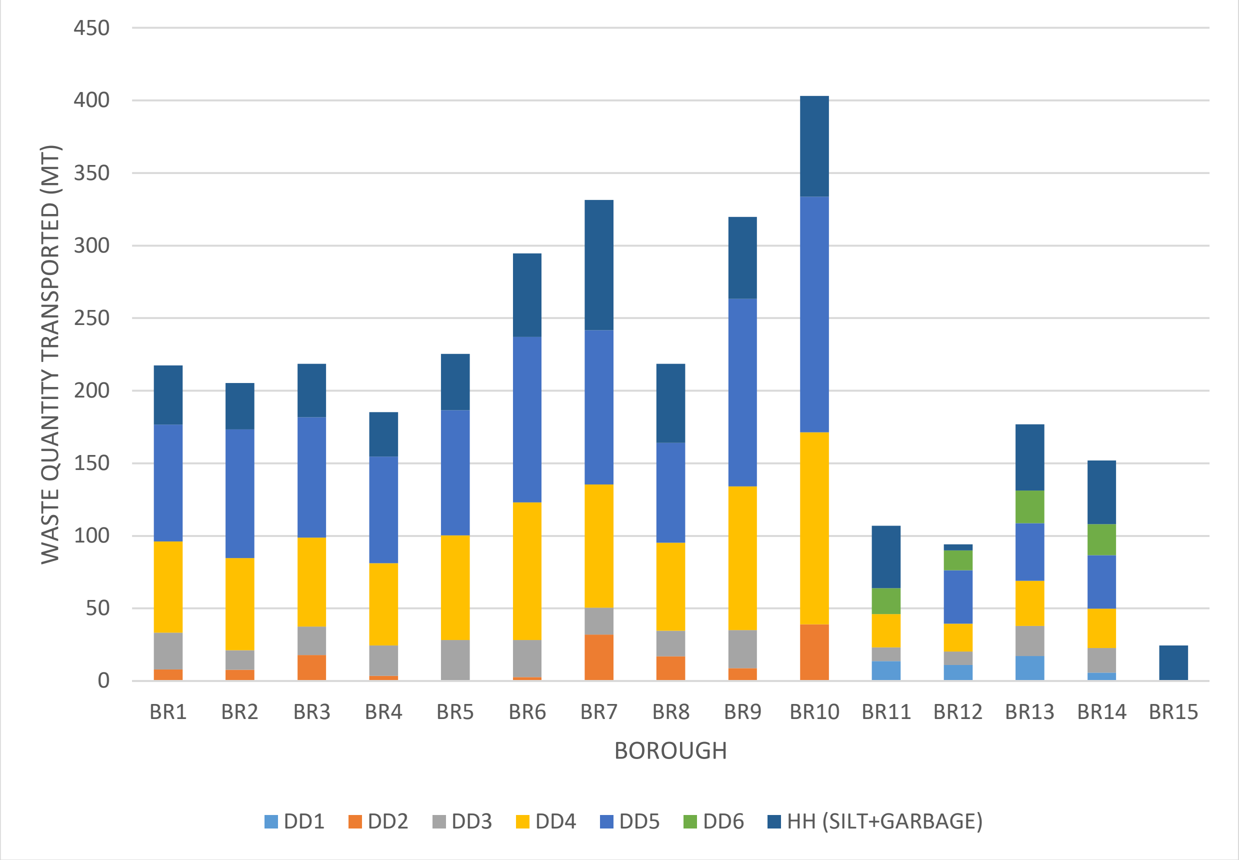

Figure 6.17 Quantity of waste transported by different vehicle types from different boroughs (Run 3)

Figure 6.17 and Table 6.61 reveals that DD1, DD2, DD3, DD4, DD5, DD6, HH transfers 1.5%, 4.3%, 7.97%, 28.00%, 34.85%, 2.37%, 21.04% of garbage respectively. DD5 takes highest amount of garbage, since its number of vehicles is high (Table 6.43) and maximum garbage carrying range is also high (Table 6.33), while the hired vehicles transport waste as per their minimum garbage carrying range. These results are almost similar to that obtained in Run 2.

The results of waste quantity (garbage + silt) transported to different transfer station/disposal sites and subjected to different processing techniques (garbage) is shown in Figure 6.18.

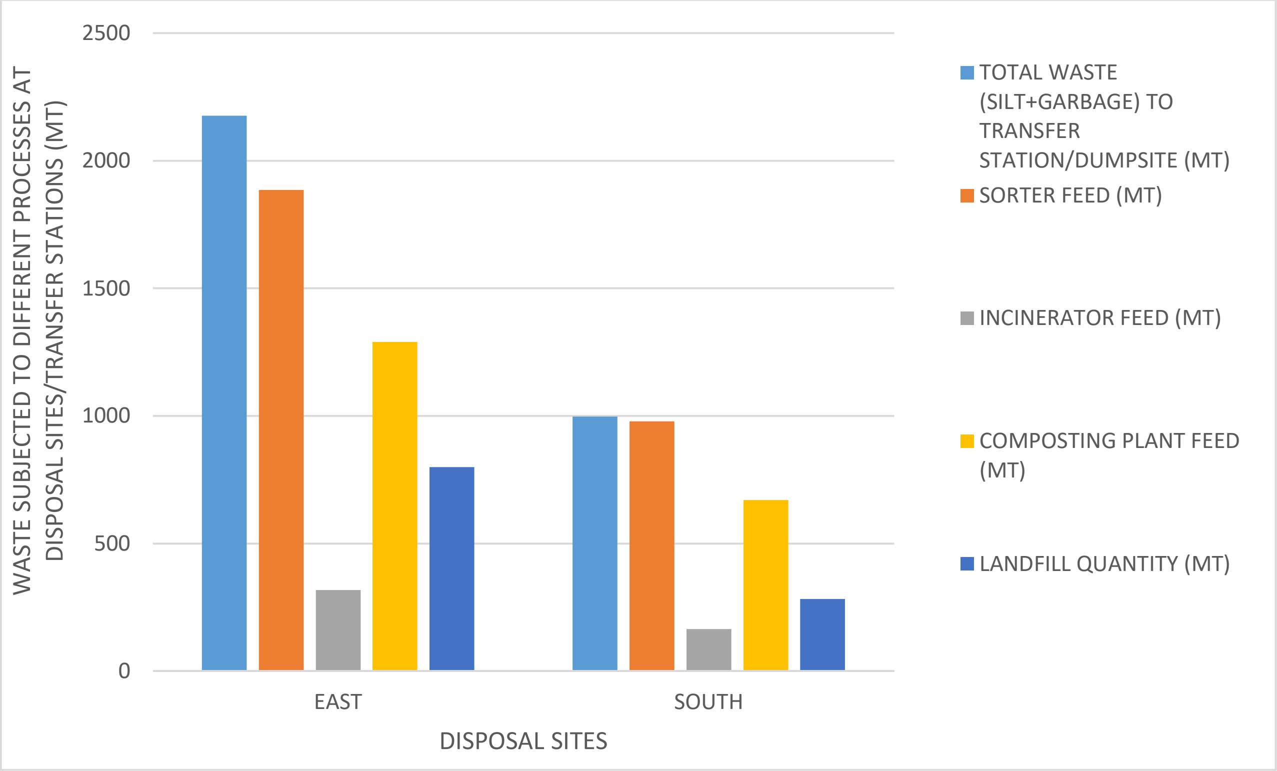

Figure 6.18 Waste quantity entering different transfer stations/disposal sites and processing plants (Run 3)

Figure 6.18 and Table 6.59 illustrates that 65.83% of waste has entered East transfer station, and 34.17% of waste has entered South transfer station respectively. Whereas in Run 1, 57.71% of waste, 13.99% of waste and 28.3% of waste are going to East, North and South landfill. For Run 2, 43.53% and 56.47% of disposable waste enters North and South landfills respectively. From these three Runs we can say that our second priority of landfill site construction will be South landfill site. The South landfill site's capacity should be more than or equal to 56.47%.

Garbage from boroughs 1 to 7 and borough 12 have been transferred to East transfer station since distance of these borough centres to East transfer station is the least (Table 6.31); garbage from boroughs 9,10,11,13,14, and 15 have been transported to the South since South transfer station is nearest to these boroughs. Garbage from borough 8 have been transported to both East and South transfer station. Hired vehicles have been transported garbage from borough 1 to 15, to East transfer station.

Silt from borough 1 to 8 and borough 10 to 15 have been transported to East landfill, while silt from borough 9 has been transported to both East and South landfill.

Figure 6.19 shows transportation cost and incentive cost incurred by different departmental and hired vehicle.

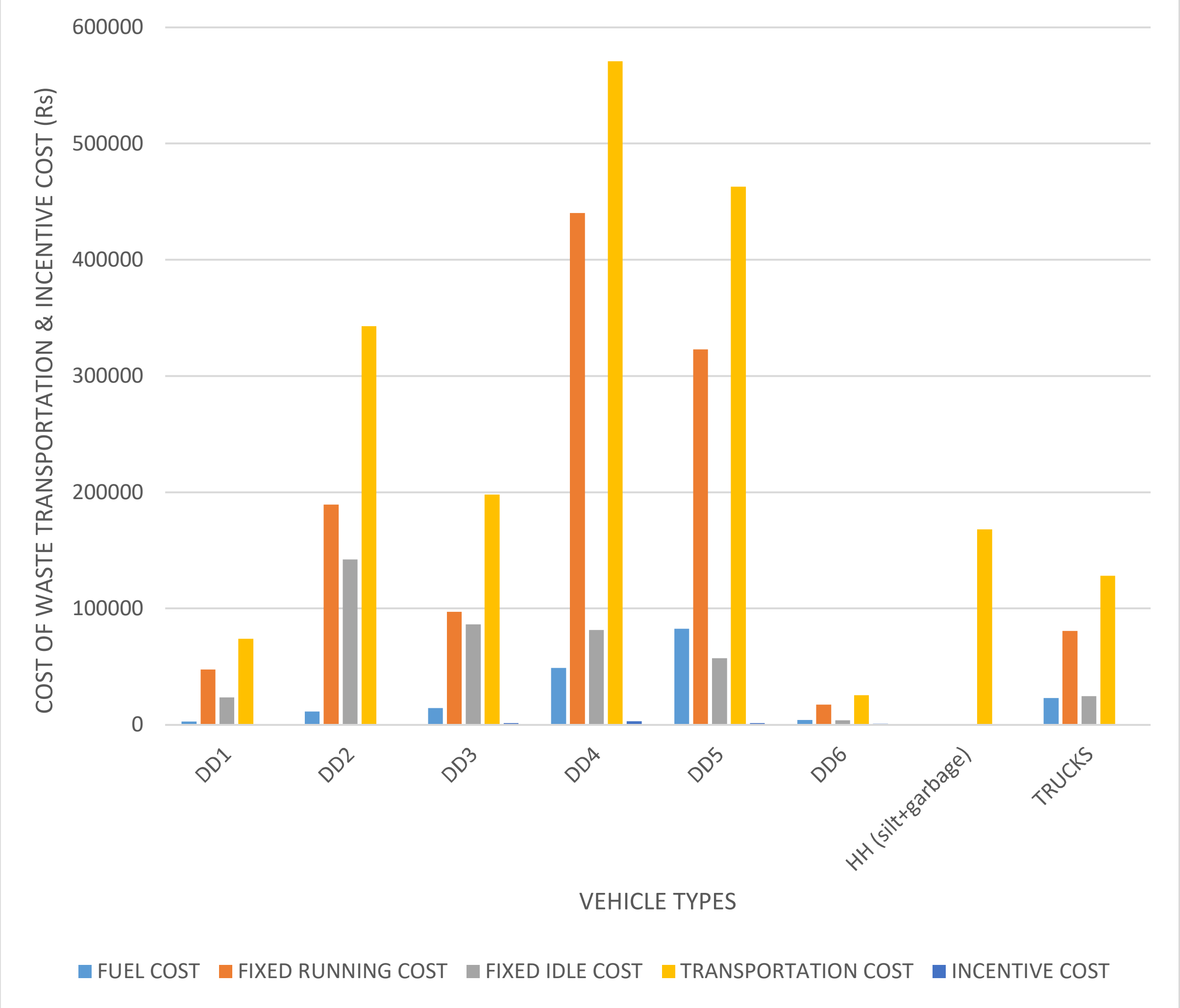

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Figure 6.19 Figure showing transportation cost and incentive cost for different vehicle types (Run 3)

In this case, both DD4 and DD3 transport garbage as per their maximum garbage carrying range (Table 6.14), except for borough 1 and borough 7. For these two boroughs, DD4 does not collect garbage as per its maximum range — DD2 takes up the balance amount for these two boroughs. This is because, although the per MT garbage transportation fuel cost is high for DD2, yet, no incentive is to be paid for transportation by DD2, while extra incentive needs to be paid for transporting by DD4 [LINGO output shows CINC (DD2) = 0; refer Table 6.60] and for these two boroughs DD4 (transportation fuel cost + incentive cost) is higher than DD2 transportation fuel cost.

Table 6.60, Table 6.61 and Figure 6.19 shows that although DD4 and DD5 transport 28.00% and 34.85% of garbage respectively, yet total transportation cost of DD4 (Rs.570807.9) is more than DD5 (Rs.462772.8). This is because fixed cost of vehicles is the highest for DD4.

RUN 4:

6.3.4 Transfer stations located near KMC boundary without considering South transfer station and South landfill site

We have considered here that, only East and North transfer stations along with landfill sites. East and North transfer station are same as Run 1 of sub chapter 6.3.1. The conditions and all other constraints are given below. We want to see the variation of total cost and other cost of the solid waste management.

6.3.4.1 Borough-Zones associated with transfer station/disposal sites

Same as Table 6.30, Table 6.31 of sub chapter 6.3.1.1

6.3.4.2 Borough-wise garbage and silt/rubbish generation

Same as table 6.10, of sub chapter 6.2.10

6.3.4.3 Types of vehicles for transportation of waste

Same as sub chapter 6.2.11

6.3.4.4 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Same as Table 6.14 of sub chapter 6.2.12

6.3.4.5 Maximum and minimum trip limits for departmental vehicles

Same as Table 6.15 of sub chapter 6.2.13

6.3.4.6 Transportation cost

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the transfer station. Additionally, cost of transporting dumpable waste from transfer station to disposal site (landfill site) needs to be considered.

6.3.4.6.1 Cost of transportation for departmental vehicles

(a) Fuel Cost
Same as Table 6.33, Table 6.34, Table 6.35, Table 6.37, Table 6.38, Table 6.40, Table 6.41, Table 6.42(only East and North) of sub chapter 6.3.1.6.1

(b) Fixed cost for departmental vehicles
Same as Table 6.43

6.3.4.6.2 Cost of transportation for hired vehicles

Same as Table 6.44, Table 6.45 of sub chapter 6.3.1.6.2.

6.3.4.7 Results and discussions

In the case of transfer station near/inside KMC boundary, it is decided that each Heavy Duty truck will have to operate maximum 4 trips at East and 3 trips at North. The total number of such trucks operating is the input data, while the program is free to choose the number of trucks required in the North and South direction — so as to optimise the total cost for a particular input of total number of trucks. Various runs were executed with different total number of trucks (however total trucks: running trucks ratio was kept constant) and the results are tabulated below:

Table 6.62 Table showing results of different runs with different total-running-idle truck Combinations

total-running-idle	S.W.M. cost (Rs/day)	SGF(E) in MT/day	SGF(N) in MT/day	SGF(S) in MT/day
20-13-7	No feasible solution			
21-14-7	**16,80,212.00**	**2642.588**	**222.1193**	-
23-15-8	16,82,409.00	2360.023	504.6840	-
24-16-8	16,88,608.00	2360.023	504.684	-
27-18-9	17,04,514.00	2360.023	504.684	-

Table 6.62 thus shows that the total cost is optimised when total number of Heavy Duty trucks is 21. An examination of the output results reveals that out of the 14 running trucks, 13 trucks are running in the East and 1 in the North direction.

A summary of the costs of different variables for 21-14-7 combination is given below in Table 6.63.

A details summary of input data use for this run is given in Table A-6.4 of Annexure 6.4 without considering South landfill site. A detailed summary of results is given in Table 6.64, Table 6.65 and Table 6.66.

Table 6.63 Output summary for transfer station near without considering South transfer station and South landfill site with total 21 Heavy Duty Trucks

Item	**Cost (Rs/day)**
Total SWM Cost (Obj. value)	16,80,212.00
Total transportation cost (CTRANSP)	19,88,577.00
Incentive cost (CINCT)	7,014.168
Landfilling cost (CTCX)	2,14,227.6
Sorting cost (CTCS)	2,92,500.9
Incineration cost (CTCI)	3,33,138.9
Composting cost (CTCC)	5,29,130.4
Revenue earned from recyclables (CTREVR)	47,000.69
Revenue earned from composting (CTREVC)	13,01,952.00
Revenue earned from incineration (CTREVI)	3,35,424.30

Here, 92.25% and 7.75% of disposable waste enters East and North landfills respectively. Because East landfill is lesser distance than North landfill from borough centre. In Run 3, 65.83% and 34.17% of disposable waste enters East and South landfills respectively. Because East landfill is lesser distance than South landfill from borough centre. For Run 2, 43.53% and 56.47% of disposable waste enters North and South landfills respectively. But in Run 1, 57.71% of waste, 13.99% of waste and 28.3% of waste are going to East, North and South landfill.

The table shows that with South landfill remaining off, total SWM cost, transportation cost and incentive cost decreases by 5.25%, 4.45% and 0.56% respectively in comparison with Run 2.Cost of landfilling, CTCX has increased by 0.097% over Run 2 — this is because in Run 2, only 43.53% of disposable waste was entering North landfill site while 56.47% was entering South, but here, 92.25%and 7.75% of disposable waste enters East and North landfills respectively.

The table also shows that with South landfill remaining off, total SWM cost, transportation cost increased by 1.21%, 0.95% respectively and incentive cost decrease by 0.64% in comparison with Run 3. The main reason of increase the transportation cost is that, here we use 21 Heavy duty trucks while in Run 3 we used 20 Heavy duty trucks. Cost of landfilling, CTCX has increased by 0.71% over Run 3 — this is because in Run 3, only 65.83% of disposable waste was entering East landfill site while 34.17% was entering South, but here, 92.25%and 7.75% of disposable waste enters East and North landfills respectively. Because operating cost of North landfill sites is slightly more than East and South for that cost of landfilling is increased over Run 3.

Table 6.64 Waste transported to different transfer stations/disposal sites and undergoing different processes

Dumpsites/ Transfer station	Total waste(silt+ garbage) to dumpsites /transfer station (MT)	Sorter feed (MT)	Incinerator feed (MT)	Composting plant feed (MT)	Landfill quantity (MT)
EAST	2951.438	2642.588	445.012	1808.059	1022.679
NORTH	222.119	222.119	37.405	151.974	60

Table 6.65 Analysis of waste (silt & garbage) transported by departmental and hired vehicles

	WASTE TRANSPORTED BY VEHICLES IN MT								
BR.	**DD1**	**DD2**	**DD3**	**DD4**	**DD5**	**DD6**	**HH (Silt + Garbage)**	**Borough wise total Dept. vehicle**	**HH (Garbage)**
1	0	27.479	25.516	53.781	69.876	0	40.738	176.651	19.628
2	0	23.116	13.484	63.568	73.2	0	31.893	173.366	19.263
3	0	17.769	19.743	61.203	82.921	0	36.884	181.636	15.7944
4	0	3.437	20.966	56.711	73.552	0	30.535	154.665	17.185
5	0	0	28.197	72.151	86.249	0	38.733	186.597	20.733
6	0	0	25.764	94.812	116.453	0	57.511	237.029	20.6112
7	0	31.88	18.597	85.014	106.27	0	89.610	241.759	23.9103
8	0	11.311	17.643	60.692	74.434	0	54.430	164.079	12.3501
9	0	8.778	26.334	98.899	129.33	0	56.46	263.34	29.26
10	0	12.23	0	132.31	189.01	0	69.561	333.549	37.061
11	13.65	0	9.45	23.1	0	17.85	42.84	64.05	40.95
12	11.027	0	9.189	19.297	36.756	13.78	4.1978	90.0522	1.8378
13	17.275	0	20.73	31.095	39.732	22.46	45.6	131.29	41.46
14	5.688	0	17.064	27.017	36.971	21.33	43.967	108.07	34.12728
15	0	0	0.244	0	0	0	24.216	0.244	24.156
Total	**47.64**	**136**	**252.92**	**879.65**	**1114.75**	**75.42**	**667.18**	**2506.38**	**358.3271**

Table 6.66 Break-up of waste transportation cost and incentive cost by different departmental and hired vehicles

Vehicle types	Fuel cost (Rs)	Fixed running cost (Rs)	Fixed idle cost(Rs)	Total transportation cost (Rs)	Incentive cost(Rs)
DD1	6253.304	47621.43	23575.86	77450.59	484.1904
DD2	8711.707	189320.5	142153.4	340185.6	0
DD3	14880.41	97167.36	86474.88	198522.7	1273.809
DD4	49539.53	440349.8	81582.72	571472.1	2720.234
DD5	84922.32	322824.9	57285.8	465033	1610.785
DD6	9038.585	17327.7	3852.7	30218.99	925.1494
HH (silt+garbage)	0	0	0	166355.9	0
TRUCKS	27994.06	86787.12	24556.91	139338.1	0

Quantity of waste transported by individual vehicle types from different boroughs to the transfer stations/disposal sites is depicted in Figure 6.20.

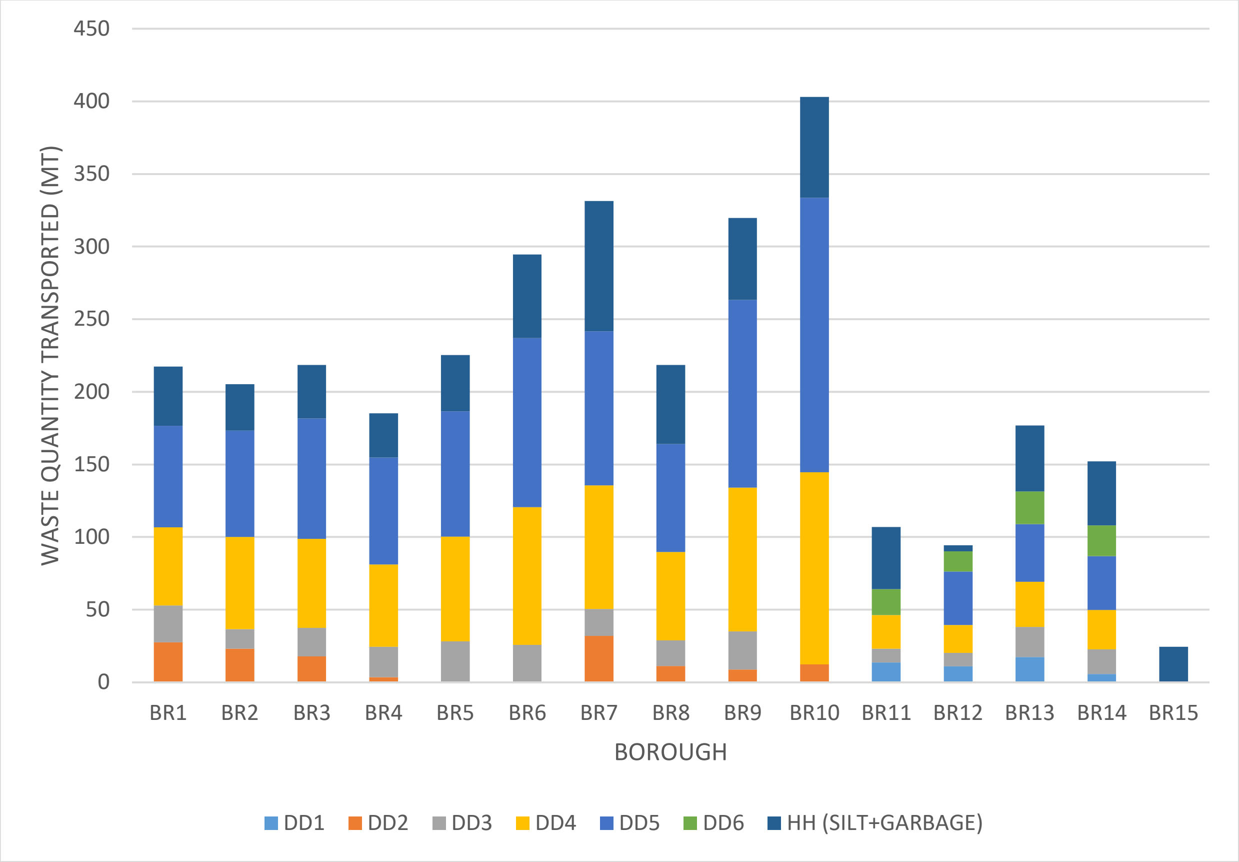

Figure 6.20 Quantity of waste transported by different vehicle types from different boroughs (Run 4)

Figure 6.20 and Table 6.65 reveals that DD1, DD2, DD3, DD4, DD5, DD6, HH transfers 1.5%, 4.3%, 7.97%, 28.00%, 34.85%, 2.37%, 21.04% of garbage respectively. DD5 takes highest amount of garbage, since its number of vehicles is high (Table 6.43) and maximum garbage carrying range is also high (Table 6.44), while the hired vehicles transport waste as per their minimum garbage carrying range. These results are almost similar to that obtained in Run 2 and Run 3.

The results of waste quantity (garbage + silt) transported to different transfer station/disposal sites and subjected to different processing techniques (garbage) is shown in Figure 6.21.

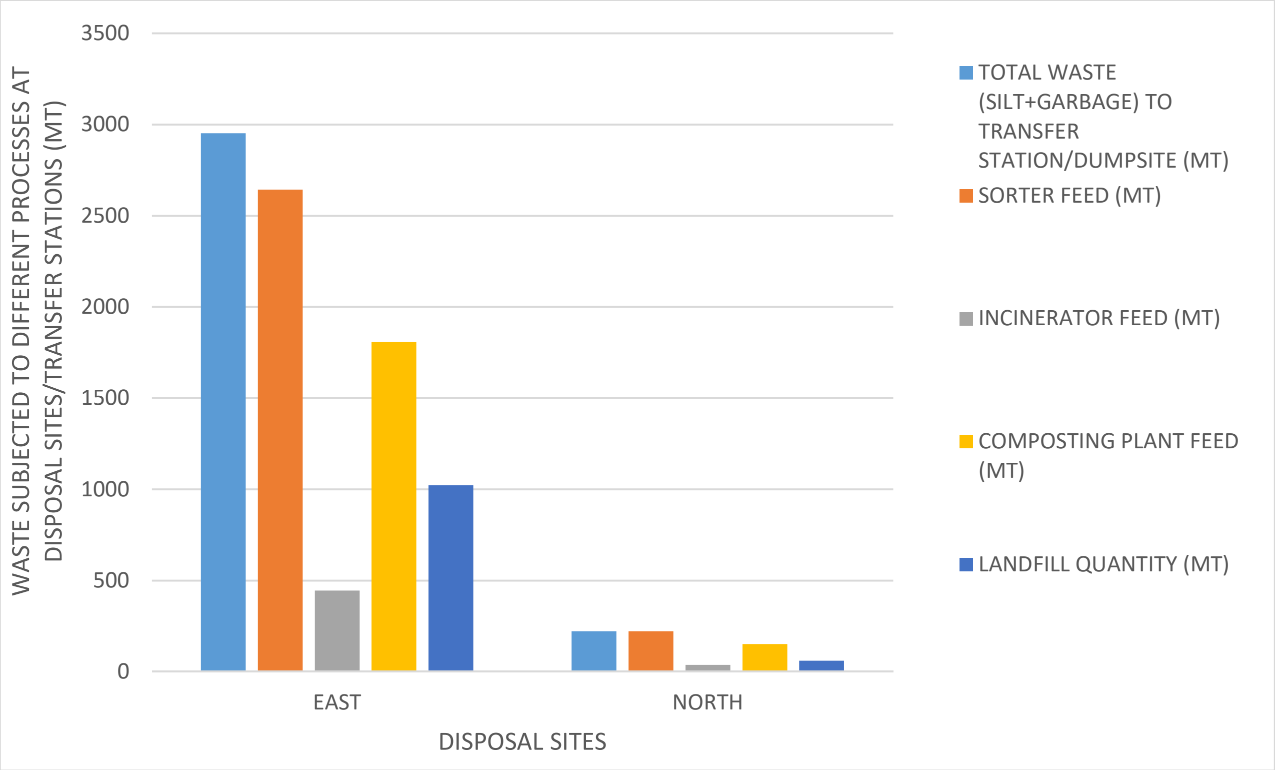

Figure 6.21 Waste quantity entering different transfer stations/disposal sites and processing plants (Run 4)

Figure 6.21 and Table 6.64 illustrates that 92.25% of waste has entered East transfer station, and 7.75% of waste has entered North transfer station respectively. In Run 3, 65.83% and 34.17% of disposable waste enters East and South landfills respectively. Because East landfill is lesser distance than South landfill from borough centre. But in Run 1, 57.71% of waste, 13.99% of waste and 28.3% of waste are going to East, North and South landfill. From these Run 1, Run 4, and Run 3 we can suggest that East landfill site should be design with a capacity of 92.25% of disposable waste.

Figure 6.21 and Table 6.64 illustrates that 92.25% of waste has entered East transfer station, and 7.75% of waste has entered North transfer station respectively. For Run 2, 43.53% and 56.47% of disposable waste enters North and South landfills respectively. But in Run 1, 57.71% of waste, 13.99% of waste and 28.3% of waste are going to East, North and South landfill. From these Run 1, Run 2, and Run 4 we can suggest that North landfill site should be design with a capacity of 43.53% of disposable waste.

Here garbage from boroughs 1 has been transferred to North transfer station since distance of these borough centres to East transfer station is the least (Table 6.30); garbage from boroughs 3 to 15 have been transported to the East since East transfer station is nearest to these boroughs. Garbage from borough 2 have been transported to both East and North transfer station. Hired vehicles have been transported garbage from borough 1 to 15, to East transfer station.

Silt from borough 1 to 8 and borough 10 to 15 have been transported to East landfill, while silt from borough 9 has been transported to both East and South landfill.

Figure 6.22 shows transportation cost and incentive cost incurred by different departmental and hired vehicle.

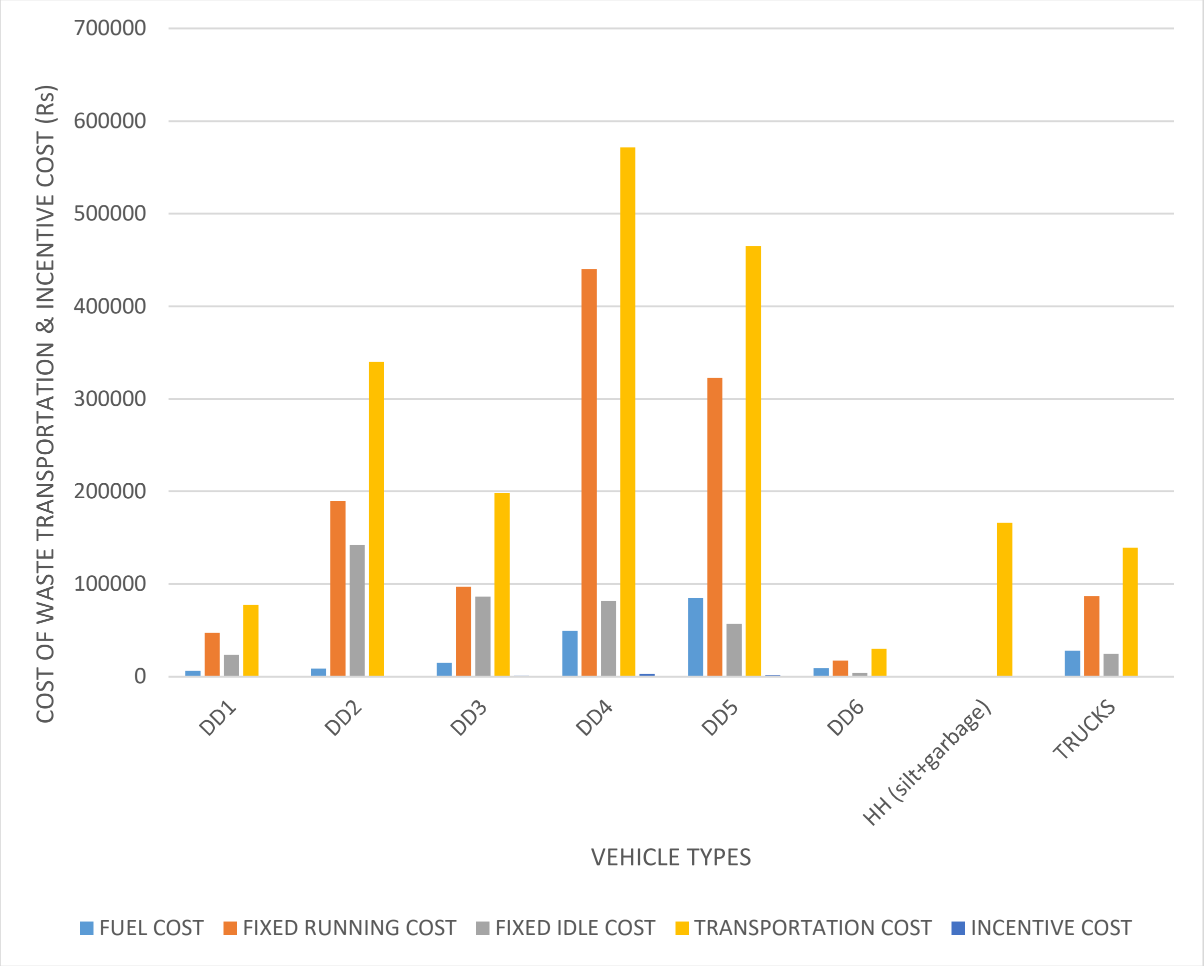

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Figure 6.22 Figure showing transportation cost and incentive cost for different vehicle types (Run 4)

In this case, both DD4 and DD3 transport garbage as per their maximum garbage carrying range (Table 6.14), except for borough 1 and borough 7. For these two boroughs, DD4 does not collect garbage as per its maximum range — DD2 takes up the balance amount for these two boroughs. This is because, although the per MT garbage transportation fuel cost is high for DD2, yet, no incentive is to be paid for transportation by DD2, while extra incentive needs to be paid for transporting by DD4 [LINGO output shows CINC (DD2) = 0; refer Table 6.66] and for these two boroughs DD4 (transportation fuel cost + incentive cost) is higher than DD2 transportation fuel cost.

Table 6.65, Table 6.66 and Figure 6.22 shows that although DD4 and DD5 transport 28.00% and 34.85% of garbage respectively, yet total transportation cost of DD4 (Rs.571472.1) is more than DD5 (Rs.465033). This is because fixed cost of vehicles is the highest for DD4.

In Run 4 we noticed that if we consider both East and North landfill sites only and assuming that South landfill site is not functioning then our total SWM cost will be Rs. 16,80,212.00 per day basis. Total 92.25% and 7.75% of disposable waste enter into East and North landfill site along with transfer station respectively. But in practical situation if any accidental condition occur and our one landfill site (say South) is not in working condition then according to Run 4 solution East landfill site has to take 92.25% of disposable waste whereas North landfill site takes 7.75%. For that we have to design East landfill site as 92.25% capacity basis. But this is not realistic because in normal condition according to Run 1 when all landfill sites are in working condition, only 57.71% waste has transferred to East landfill site. As a solution we have to restrict the maximum capacity of East landfill site along with transfer station. The restricted capacity of East landfill site will be according to the result of Run 3's East landfill capacity that is 65.83% of disposable waste.

So in Run 5 we have again solved the model by restricting the East landfill capacity, East transfer station capacity, Composting plant and Incinerator plant capacity of East transfer station.

RUN 5:

6.3.5 Transfer stations located near KMC boundary without considering South transfer station and South landfill site with restricted capacity of East landfill site along with transfer station

We have considered here that, only East and North transfer stations along with landfill sites. East and North transfer station are same as Run 1 of sub chapter 6.3.1. The conditions and all other constraints are given below. We have restricted East landfill site capacity, East transfer station capacity, Composting plant and Incinerator plant capacity of East transfer station. We want to see the variation of total cost and other cost of the solid waste management.

6.3.5.1 Borough-Zones associated with transfer station/disposal sites

Same as Table 6.30, Table 6.31 of sub chapter 6.3.1.1

6.3.5.2 Borough-wise garbage and silt/rubbish generation

Same as table 6.10, of sub chapter 6.2.10

6.3.5.3 Types of vehicles for transportation of waste

Same as sub chapter 6.2.11

6.3.5.4 Maximum and minimum limit (in fraction) of garbage quantity carried by different vehicles

Same as Table 6.14 of sub chapter 6.2.12

6.3.5.5 Maximum and minimum trip limits for departmental vehicles

Same as Table 6.15 of sub chapter 6.2.13

6.3.5.6 Transportation cost

Cost of waste transportation includes transportation cost for departmental and hired vehicles from storage points i.e. container points or vat points to the transfer station. Additionally, cost of transporting dumpable waste from transfer station to disposal site (landfill site) needs to be considered.

6.3.5.6.1 Cost of transportation for departmental vehicles

(a) Fuel Cost

Same as Table 6.33, Table 6.34, Table 6.35, Table 6.37, Table 6.38, Table 6.40, Table 6.41, Table 6.42(only East and North) of sub chapter 6.3.1.6.1

(b) Fixed cost for departmental vehicles
Same as Table 6.43

6.3.5.6.2 Cost of transportation for hired vehicles

Same as Table 6.44, Table 6.45 of sub chapter 6.3.1.6.2.

A details summary of input data use for this run is given in Table A-6.5 of Annexure 6.5 without considering South landfill site.

6.3.5.7 Results and discussions

In the case of transfer station near/inside KMC boundary, it is decided that each Heavy Duty truck will have to operate maximum 4 trips at East and 3 trips at North. The total number of such trucks operating is the input data, while the program is free to choose the number of trucks required in the East and North direction — so as to optimise the total cost for a particular input of total number of trucks. Various runs were executed with different total number of heavy duty trucks (however total trucks: running trucks ratio was kept constant) and the results are tabulated below:

Table 6.67 Table showing results of different runs with different total-running-idle heavy duty truck Combinations

total-running-idle	S.W.M. cost (Rs.)	SGF(E) in MT	SGF(N) in MT	SGF(S) in MT
21-14-7	No feasible solution			
22-15-7	**16,86,596.00**	**1871.215**	**993.4921**	-
23-16-7	16,90,402.00	1900.00	964.707	-
25-17-8	17,00,109.00	1900.00	964.707	-

Table 6.67 thus shows that the total cost is optimised when total number of Heavy Duty trucks is 22. An examination of the output results reveals that out of the 15 running trucks, 10 trucks are running in the East and 5 in the North direction.

A summary of the costs of different variables for 22-15-7 combination is given below in Table 6.68. A detailed summary of results is given in Table 6.69, Table 6.70 and Table 6.71.

Table 6.68 Output summary for transfer station near without considering South transfer station and South landfill site with restricted capacity of East landfill site with total 22 Heavy Duty Trucks

Item	Cost (Rs/day)
Total SWM Cost (Obj. value)	16,86,596.00
Total transportation cost (CTRANSP)	19,93,482.00
Incentive cost (CINCT)	7,014.168
Landfilling cost (CTCX)	2,15,706.2
Sorting cost (CTCS)	2,92,500.9
Incineration cost (CTCI)	3,33,138.9
Composting cost (CTCC)	5,29,130.4
Revenue earned from recyclables (CTREVR)	47,000.69
Revenue earned from composting (CTREVC)	13,01,952.00
Revenue earned from incineration (CTREVI)	3,35,424.30

As because we restrict the capacity of East landfill site (i.e. 2000 MT) so from output result it is clear that 1871.215 MT (65.32%) disposable waste is going to East landfill site and 993.49 MT (34.68%) disposable waste is going to North landfill site. Whereas in Run 4, 92.25% and 7.75% of disposable waste enters East and North landfills respectively.

Here we use total 22 number of heavy duty trucks, 15 trucks are running and among them 10 trucks are running in East and 5 trucks are running in North landfill site. But in Run 4 total number of trucks was 21 and 14 are running condition and among them 13 trucks are in East and 1 truck is in North landfill site respectively. For that reason total transportation cost is increased 0.25% and total SWM cost is increased 0.38% in Run 5 as compare with Run 4. The increased amount of total SWM cost is Rs. 6384.00 per day.

The landfilling cost (CTCX) is more in here (Run 5) as compare with Run 4 as because operating cost of North landfill sites is slightly more than East and 26.93% more waste is going to North landfill site than Run 4.

Table 6.69 Waste transported to different transfer stations/disposal sites and undergoing different processes

Dumpsites/ Transfer station	Total waste(silt+ garbage) to dumpsites /transfer station (MT)	Sorter feed (MT)	Incinerator feed (MT)	Composting plant feed (MT)	Landfill quantity (MT)
EAST	2165.753	1871.215	315.1126	1280.285	800.00
NORTH	1007.804	993.4921	167.304	679.747	282.6794

Table 6.70 Analysis of waste (silt & garbage) transported by departmental and hired vehicles

	WASTE TRANSPORTED BY VEHICLES IN MT								
BR.	**DD1**	**DD2**	**DD3**	**DD4**	**DD5**	**DD6**	**HH (silt+garbage)**	**Borough wise total Dept. vehicle**	**HH (Garbage)**
1	0	27.479	25.516	53.781	69.876	0	40.738	176.651	19.628
2	0	23.116	13.484	63.568	73.2	0	31.893	173.366	19.263
3	0	17.769	19.743	61.203	82.921	0	36.884	181.636	15.7944
4	0	3.437	20.966	56.711	73.552	0	30.535	154.665	17.185
5	0	0	28.197	72.151	86.249	0	38.733	186.597	20.733
6	0	0	25.764	94.812	116.45	0	57.511	237.029	20.6112
7	0	31.88	18.597	85.014	106.27	0	89.610	241.759	23.9103
8	0	11.311	17.643	60.692	74.434	0	54.430	164.079	12.3501
9	0	8.778	26.334	98.899	129.33	0	56.46	263.34	29.26
10	0	12.23	0	132.31	189.01	0	69.561	333.549	37.061
11	13.65	0	9.45	23.1	0	17.85	42.84	64.05	40.95
12	11.03	0	9.189	19.297	36.756	13.78	4.1978	90.0522	1.8378
13	17.27	0	20.73	31.095	39.732	22.46	45.6	131.29	41.46
14	5.688	0	17.064	27.017	36.971	21.33	43.967	108.07	34.12728
15	0	0	0.244	0	0	0	24.216	0.244	24.156
Total	**47.64**	**136**	**252.92**	**879.65**	**1114.75**	**75.42**	**667.18**	**2506.38**	**358.3271**

Table 6.71 Break-up of waste transportation cost and incentive cost by different departmental and hired vehicles

Vehicle types	**Fuel cost (Rs)**	**Fixed running cost (Rs)**	**Fixed idle cost(Rs)**	**Total transportation cost (Rs)**	**Incentive cost(Rs)**
DD1	6253.304	47621.43	23575.86	77450.59	484.1904
DD2	8650.788	189320.5	142153.4	340185.6	0
DD3	15014.06	97167.36	86474.88	198522.7	1273.809
DD4	48987.76	440349.8	81582.72	570920.3	2720.234
DD5	82048.25	322824.9	57285.8	462159	1610.785
DD6	9038.585	17327.7	3852.7	30218.99	925.1494
HH (silt+garbage)	0	0	0	167787.1	0
TRUCKS	28622.02	92986.2	24556.91	146165.1	0

Quantity of waste transported by individual vehicle types from different boroughs to the transfer stations/disposal sites is depicted in Figure 6.23.

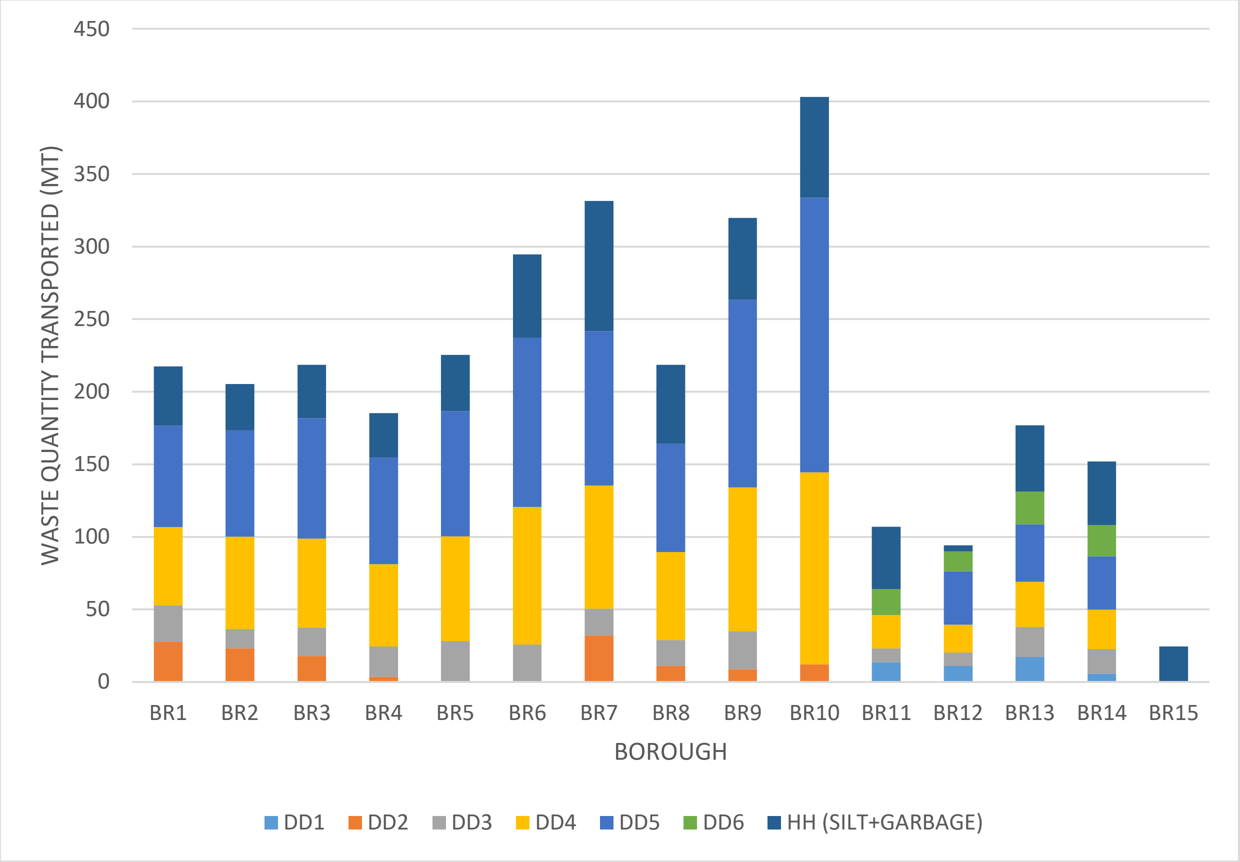

Figure 6.23 Quantity of waste transported by different vehicle types from different boroughs (Run 5)

Figure 6.23 and Table 6.70 reveals that DD1, DD2, DD3, DD4, DD5, DD6, HH transfers 1.5%, 4.3%, 7.97%, 28.00%, 34.85%, 2.37%, 21.04% of garbage respectively. DD5 takes highest amount of garbage, since its number of vehicles is high (Table 6.43) and maximum garbage carrying range is also high (Table 6.44), while the hired vehicles transport waste as per their minimum garbage carrying range. These results are almost similar to that obtained in Run 2 and Run 3.

The results of waste quantity (garbage + silt) transported to different transfer station/disposal sites and subjected to different processing techniques (garbage) is shown in Figure 6.24.

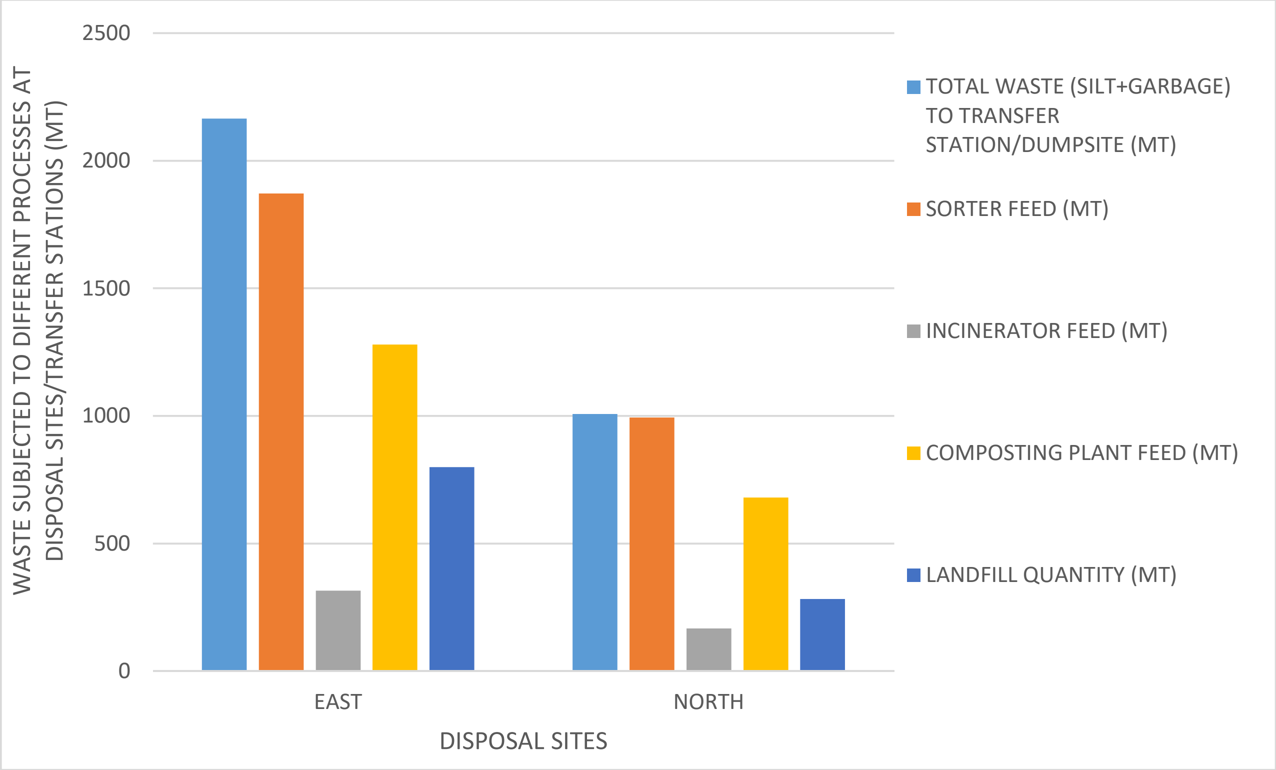

Figure 6.24 Waste quantity entering different transfer stations/disposal sites and processing plants (Run 5)

Figure 6.24 and Table 6.69 illustrates that 65.32% of waste has entered East transfer station, and 34.68% of waste has entered North transfer station respectively. Garbage from boroughs 1 to 5 has been transferred to North transfer station since distance of these borough centres to North transfer station is the least (Table 6.31); garbage from boroughs 7 to 15 have been transported to the East since East transfer station is nearest to these boroughs. Garbage from borough 6 have been transported to both East and North transfer station. Hired vehicles have been transported garbage from borough 1 to 15, to East transfer station.

Silt from borough 2 to 15 have been transported to East landfill, while silt from borough 1 has been transported to both East and North landfill.

Figure 6.25 shows transportation cost and incentive cost incurred by different departmental and hired vehicle.

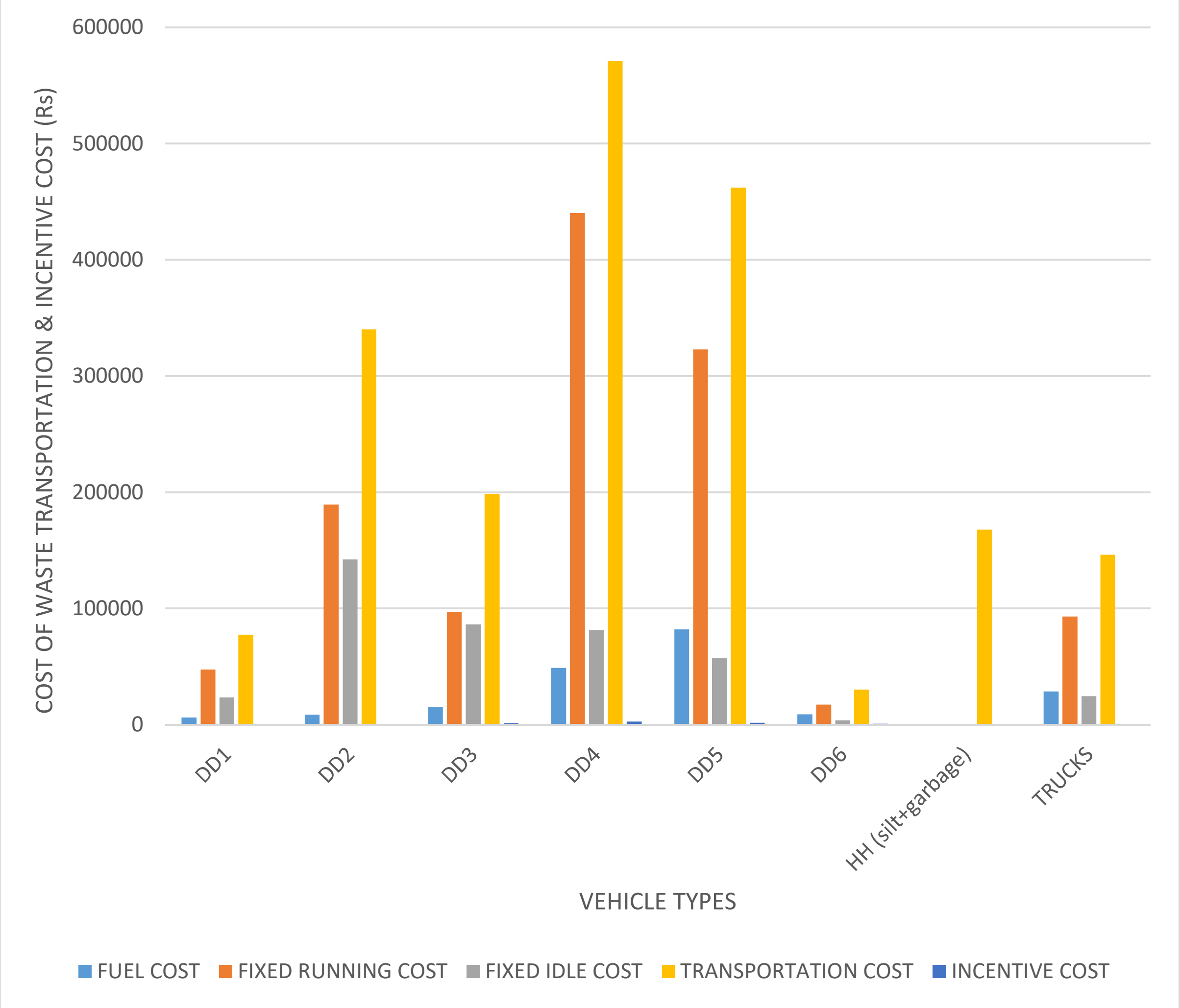

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Figure 6.25 Figure showing transportation cost and incentive cost for different vehicle types (Run 5)

In this case, both DD4 and DD3 transport garbage as per their maximum garbage carrying range (Table 6.14), except for borough 1 and borough 7. For these two boroughs, DD4 does not collect garbage as per its maximum range — DD2 takes up the balance amount for these two boroughs. This is because, although the per MT garbage transportation fuel cost is high for DD2, yet, no incentive is to be paid for transportation by DD2, while extra incentive needs to be paid for transporting by DD4 [LINGO output shows CINC (DD2) = 0; refer Table 6.66] and for these two boroughs DD4 (transportation fuel cost + incentive cost) is higher than DD2 transportation fuel cost.

Table 6.70, Table 6.71 and Figure 6.25 shows that although DD4 and DD5 transport 28.00% and 34.85% of garbage respectively, yet total transportation cost of DD4 (Rs. 570920.3) is more than DD5 (Rs. 462159). This is because fixed cost of vehicles is the highest for DD4.

From the above table and figure of Run 1, Run 2, Run 3, Run 4, Run 5, we can suggest that maximum capacity of East landfill site should be as per Run 3's capacity i.e. 65.83%. So we should design our East landfill site's capacity according to 66% of disposable waste (i.e 1950 MT/day). For North and South landfill site the maximum capacity should be as per Run 2's capacity i.e. 43.53% of disposable waste (1250 MT/day) and 56.47% of disposable waste (1650 MT/day) respectively.

If we do not restrict the East landfill capacity then as per Run 4 when South landfill site is not functioning then 92.25% of disposal waste will go to East landfill site. For that reason we could not design the East landfill site with 92.25% capacity. In our model we are assuming three landfill site. So most of the time three landfill sites will be in working condition. When three landfill site are in working condition then as per Run 1, 57.62% of disposable waste will go to East landfill site. In normal condition 57.62% capacity is required. So it will be unnecessary for us to design the East landfill site of a high amount of capacity. Rather we can modified our case and restrict the capacity. Though it will increase our cost some amount in here Rs. 6384.00 per day basis but still it will be more realistic than design with a huge amount of capacity.

7. CONCLUTION

The huge generation of MSW and its improper management, especially in developing countries, has become a serious problem for the society as the urban local bodies. Improper management and open dumping of MSW leads to high emission of GHGs like CH_4, CO_2 and other toxic gases. Also huge generation of highly polluted leachate degrades the natural resources like air, water and land. It has been realized gradually that existing conventional MSW management is unable to fulfil the goal of sustainable development. Integrated MSW management system is a need of now a days to achieve this goal, and there is a concerned effort to develop a methodology to find optimized path to shift towards integrated MSW management approach. In a developing country like India, a major metropolitan city Kolkata is considered for developing this methodology in this model.

In chapter 5 we develop the equation to generate the model and for the objective function we have taken Cost of transportation, Incentive cost, Sorting cost, Incineration cost, Composting cost, Landfilling cost, Revenue earned from recycling, Revenue earned from composting, Revenue earned from incineration. Our objective of this model is to minimize the cost of SWM.

For running the model we have taken data from various research paper. In the sub chapter 6.1 there we include data which are taken.

In first part of chapter 6 we validate our model with KMC 2007 data and solid waste management cost. After validation of the model, it shows that the model predicts the total SWM cost is (Rs. 9,86,836.1) where in actual condition the cost was (Rs. 10,66,867.93). So the optimized cost is 7.5% less than actual cost of SWM of KMC 2007. Total transportation cost (including incentive) for departmental and hired vehicles for actual MSW management system by KMC was Rs 8,15,225.07/day in 2007, while validation model gave Rs. 7,35,928.75/day. Model analysis provides the optimised value for 2007 scenario; so there was an opportunity to minimise transportation costs by about 10%. Model predicts a garbage transportation cost of Rs. 2,23,864.7/day by hired vehicles, which is about 5% lower than actual cost (Rs. 2,36,000/day). So the model is ok.

In Run 1 where we have considered 3 nos. of transfer station and 3 nos. of landfill sites along East, North, and South direction. It is our proposed situation, and the result come out from the model is that the total SWM cost will be Rs. 16,39,421.00 per day, a total of 57.62% of waste has entered East landfill, while 13.99% and 28.3% of waste has entered North and South landfill site respectively. From these results it is evident that the construction of East landfill site should be the first priority. Here the cost will be minimum compare to our next case because here we consider three transfer station and three landfill sites.

As because it is a proposed case, so if we construct 3 nos. of transfer station and 3 nos. of landfill then only we can manage our generated solid waste in a proper manner with minimizing the total cost of SWM. But in practical situation we may not construct all transfer station and landfill site at the same time. We have to construct transfer station along with landfill one by one or any two at a time. For that purpose we do not know which two transfer stations and landfill sites have to construct first for minimizing the cost. Besides in any accidental condition (say technical fault in the bio/thermal processing units, garbage dump landslide, public agitation against accidental spills etc.) one landfill may not be used for depositing purpose. For these cases we have to know the operational change and capacity increment of the other landfill along with their cost implications.

Comparing total SWM cost and transportation cost of Run 2 (considering only North and South transfer station and landfill), Run 3 (considering only East and South transfer station and landfill), Run 4 (considering only East and North transfer station and landfill) we can say that minimum cost come out for the case Run 3(Rs. 1660125.00 per day), then Run 4(Rs. 1680212.00), then Run 2(Rs. 1773316.00). Total cost of Run 3, is 6.38 % less than Run 2, and 1.19% less than Run 4. Besides total transportation cost of Run 3 is than 5.4% than Run 2 and 0.94% less than Run 4 because in Run 3 total trucks required is 20 where for Run 2 and Run 4 , total 21 number of trucks required for each. So according to construction purpose Run 3 is most realistic model. Then comes Run 4 and at last Run 2. So according to the cost minimization sense we can conclude that we should construct both East and South transfer stations and Landfill sites first. After that we should construct North transfer station and landfill site.

From the above analysis we can also conclude that East landfill site is the most important landfill site among the three landfill sites. Then comes South landfill site and at last North landfill site. If any problem occur in East landfill site or in East transfer station then we should have to fix the problem as soon as possible.

In any accidental condition one landfill may not use for depositing purpose, then the total waste will have to deposit in two other landfill. So landfill capacity will increase for that case. For that reason we have to consider that thing for design the capacity of landfill site.

In Run 1, when three landfill sits along with transfer stations are in working condition then 57.71% of waste, 13.99% of waste and 28.3% of waste has transferred to East, North and South landfill site. In Run 2, without considering East landfill site the capacity of north and South landfill site's will increase and it shows 43.53% and 56.47% of disposable waste enters North and South landfills respectively. In Run 3, without considering North landfill site, 65.83% of waste has entered East transfer station, and 34.17% of waste has entered South transfer station. In Run 4, without considering South landfill site, 92.25% of waste has entered East transfer station, and 7.75% of waste has entered North transfer station respectively.

Comparing Run 1, Run 2, and Run 3 we can conclude that South landfill site's capacity should be more than or equal to 56.47%.

Comparing Run 1, Run 2, and Run 4 we can conclude that North landfill site should be design with a capacity of 43.53% of disposable waste.

Comparing Run 1, Run 4, and Run 3 we can conclude that East landfill site should be design with a capacity of 92.25% of disposable waste.

But providing a design capacity of 92.25% for East landfill site is not realistic. The use of these amount of design capacity is only when South landfill site is not in working condition. Normally when we consider three landfill site then 57.71 % waste has transferred to East landfill site. That means if we design East landfill site as 92.25% capacity then most of the time (92.25 – 57.71)% = 34.54% capacity will be in unused condition. Besides if North landfill site is not in working condition then 65.83% waste has transferred to East landfill site. As a solution we have to restrict the maximum capacity of East landfill site along with transfer station and again run the model (Run 5). The restricted capacity of East landfill site will be according to the result of Run 3's East landfill capacity that is 65.83% of disposable waste.

AS a result from Run 5 total SWM cost (Rs. 16,86,596.00) is increased 0.38% as compare with Run 4 (Rs. 1680212.00). The increased amount of total SWM cost is Rs. 6384.00 per day. It is more realistic than Run 4.

So design capacity of East landfill site will be 65.83% of disposable waste. We have to consider Run 5 instead of Run 4 when South landfill site will not be used for depositing purpose.

8. FUTURE SCOPE OF WORK

Based on the scope and findings of the present investigation, the following suggestions are made for future studies.

1. The study can be extended using geographic information system (GIS) based management information system (MIS) for municipal solid waste management.

2. Pollution generated from landfill solid waste can be included in the model and subsequent equation can be developed.

3. Potential environmental impact of all pollutants emitted from MSW management system can be estimated by Life Cycle Impact Assessment (LCIA) methodology or Waste Reduction Algorithm (WAR) methodology and compare between existing and proposed system.

4. Multi-objective optimization model considering competing objectives like SWM cost, pollutants emission etc. may be adopted in the future study.

5. Social and environmental cost benefit analysis of MSW management can be done in future study.

6. In future Life Cycle Assessment study of MSW management can be used as an important tool for future sustainable planning.

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❖ Annexure 6.1:

Table A-6.1 Borough-wise average daily garbage and silt generation in 2007

Br. No.	Total Garbage (TPD)			Total Silt+Rubbish (TPD)			Total Waste (TPD)		
	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
01	193.460	176.928	178.44	30.790	11.723	20.11	215.261	178.532	198.55
02	187.999	167.631	175.12	31.253	3.007	12.03	219.252	186.466	187.150
03	203.261	163.989	179.48	31.475	9.398	20.09	232.025	173.388	199.57
04	204.805	134.960	156.23	24.490	7.300	12.72	224.673	142.252	168.95
05	208.776	185.853	188.48	27.654	8.697	17.14	236.431	204.439	205.62
06	258.256	204.648	234.22	61.668	15.182	35.14	318.065	227.586	269.36
07	276.742	206.717	241.52	88.196	44.059	62.55	352.873	259.363	304.07
08	172.660	147.754	160.39	72.744	19.044	40.08	241.312	166.300	200.47
09	290.705	240.975	266.00	43.199	12.665	25.92	341.712	249.579	291.92
10	387.740	281.185	336.92	76.347	10.781	30.92	428.905	302.093	367.84
11	101.225	90.897	95.46	3.464	0.677	1.8	103.698	92.277	97.26
12	90.726	77.641	83.54	6.379	0.205	2.25	95.909	79.670	85.79
13	179.524	146.612	157.04	13.941	0.909	3.94	182.088	149.563	160.98
14	149.191	111.811	129.27	19.366	4.141	9.37	153.332	117.955	138.64
15	25.022	21.723	22.183	0.416	0.278	0.058	25.022	25.344	22.241

❖ Annexure 6.2:

Table A-6.2 Borough – wise minimum and maximum garbage carrying quantity range (in fraction) for departmental and hired vehicles (in 2007)

Br.	DD1		DD2		DD3		DD4		HH	
	Min fraction	Max fraction	Min fraction	Max fraction	Min fraction	Max fraction	Min fraction	Max fraction	Min fraction	Max fraction
1	0.00	0.01	0.14	0.24	0.18	0.28	0.06	0.16	0.41	0.51
2	0.00	0.00	0.15	0.25	0.12	0.22	0.00	0.00	0.57	0.67
3	0.00	0.04	0.22	0.32	0.19	0.29	0.00	0.00	0.42	0.52
4	0.00	0.00	0.10	0.20	0.00	0.11	0.21	0.31	0.48	0.58
5	0.00	0.00	0.00	0.08	0.00	0.07	0.29	0.39	0.53	0.63
6	0.00	0.00	0.00	0.11	0.00	0.04	0.13	0.23	0.70	0.80
7	0.00	0.00	0.10	0.20	0.00	0.08	0.05	0.18	0.67	0.77
8	0.00	0.00	0.15	0.25	0.18	0.28	0.00	0.00	0.53	0.63
9	0.00	0.00	0.12	0.22	0.15	0.25	0.00	0.00	0.58	0.68
10	0.00	0.00	0.13	0.23	0.00	0.00	0.00	0.00	0.77	0.87
11	0.15	0.25	0.00	0.00	0.15	0.25	0.00	0.00	0.55	0.65
12	0.20	0.30	0.00	0.00	0.20	0.30	0.00	0.00	0.45	0.55
13	0.10	0.20	0.00	0.00	0.25	0.35	0.00	0.00	0.50	0.60
14	0.05	0.15	0.00	0.00	0.25	0.35	0.00	0.00	0.65	0.75
15	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.95	1.00

❖ Annexure 6.3

Table A-6.3 Datasets prepared in Excel for use by LINGO for model validation

DUMPSITE	Recyclable fraction on Intermediate Central Sorting (ICS) feed	Direct dumpable fraction from Intermediate Central Sorting (ICS) feed	Maximum sorted fraction which is fed to incineration plant	Maximum sorted fraction which is fed to composting plant	Recyclable fraction coming out from incinerator pre-sorting	Fraction of incineration inorganic rejects	Fraction of incineration ash reject	Recyclable fraction from presorter to composting	Fraction of inorganic reject from composting	Fraction of process reject from composting	Fraction of composting plant product
D1 (E)	0.0421	0.1053	0.1684	0.6842	0.03125	0.0625	0.0919	0.0192	0.0615	0.1414	0.2657
DUMPSITE	Operational cost of sorter in each dumpsite, Rs/MT	Cost of transporting recyclable material from sorter to recycling facilty, Rs/MT	Per ton additional dumping cost from sorter (if incineration or compost not done) Rs/MT		Operational cost of composting facility including transportation cost from ICS to composting plant, Rs/MT	Transportation cost of recyclable materials from composting plant to recycling facilty, Rs/MT	Transportation cost of inorganic reject from composting plant to landfill, Rs/MT	Transportation cost of process reject from composting plant to landfill, Rs/MT			
D1 (E)	0	0	0		0	0	30	30			

Table A-6.3 Datasets prepared in Excel for use by LINGO for model validation

Maximum capacity of sorter, MT/day	Minimum capacity of sorter, MT/day	Maximum capacity of incinerator plant, MT/day	Minimum capacity of incinerator plant, MT/day	Maximum capacity of landfill site dumping ground, MT/day	Maximum capacity of composting plant, MT/day	Minimum capacity of composting plant, MT/day	Cost of landfilling (open dumping) per ton of waste, including cost of land (Rs./MT)	Operational cost of incinerator (including transportation cost from sorter to incinerator (Rs/MT)	Transportation cost from incinerator to recycling facility, (Rs/MT)	Transportation cost of incinertion ash reject to landfill, (Rs/MT)	Transportation cost of incinertion inorganic reject to landfill, (Rs/MT)	Selling price (royalty only) of compost per ton (Rs/MT waste)
5000	0	0	0	5000	151	150	95	1000	50	50	50	87.5
Items	Recycled percentage	Amount of each item coming out of sorter ICS considering per MT of total waste	Recycling rate, Rs/kg	Recycling revenue per item, Rs/MT of waste								
Paper	5.00	18.6046512	9	167.4419								
Rubber & Leather	0.34	1.26511628	0.3	0.379535								
Plastic	4.88	18.1581395	9	163.4233								
Glass	0.34	1.26511628	1	1.265116								
Metal	0.19	0.70697674	50	35.34884								
				367.8586								

Table A-6.3 Datasets prepared in Excel for use by LINGO for model validation

Revenue from recyclable from sorter (Rs/MT)	Revenue from recyclable from incinerator plant (Rs/MT)	Revenue from recyclable from composting plant (Rs/MT)	Revenue from selling per unit of electricity from W to E incinerator (Rs/kWh)	kWh units of electricity generated from one MT of MSW undergoing incineration
0	0	0	0	0

❖ Annexure 6.4

Table A-6.4 Datasets prepared in Excel for use by LINGO for transfer station near/inside KMC area

Dumpsite	Recyclable fraction on Intermediate Central Sorting (ICS) feed	Direct dumpable fraction from Intermediate Central Sorting (ICS) feed	Maximum sorted fraction which is fed to incineration plant	Maximum sorted fraction which is fed to composting plant	Recyclable fraction coming out from incinerator pre-sorting	Fraction of incineration inorganic rejects	Fraction of incineration ash reject	Recyclable fraction from presorter to composting	Fraction of inorganic reject from composting	Fraction of process reject from composting	Fraction of composting plant product
D1 (E)	0.0421	0.1053	0.1684	0.6842	0.03125	0.0625	0.0919	0.0192	0.0615	0.1414	0.2657
D2 (N)	0.0421	0.1053	0.1684	0.6842	0.03125	0.0625	0.0919	0.0192	0.0615	0.1414	0.2657
D3 (S)	0.0421	0.1053	0.1684	0.6842	0.03125	0.0625	0.0919	0.0192	0.0615	0.1414	0.2657
Dumpsite	Operational cost of sorter in each dumpsite, Rs/MT	Cost of transporting recyclable material from sorter to recycling facilty, Rs/MT	Per ton additional dumping cost from sorter (if incineration or compost not done) Rs/MT		Operational cost of composting facility including transportation cost from ICS to composting plant, Rs/MT	Transportation cost of recyclable materials from composting plant to recycling facilty, Rs/MT	Transportation cost of inorganic reject from composting plant to landfill, Rs/MT	Transportation cost of process reject from composting plant to landfill, Rs/MT			
D1 (E)	100	50	0		269	50	0	0			
D2 (N)	100	50	0		269	50	0	0			
D3 (S)	100	50	0		269	50	0	0			

Table A-6.4 Datasets prepared in Excel for use by LINGO for transfer station near/inside KMC area

Maximum capacity of sorter, MT/day	Minimum capacity of sorter, MT/day	Maximum capacity of incinerator plant, MT/day	Minimum capacity of incinerator plant, MT/day	Maximum capacity of landfill site dumping ground, MT/day	Maximum capacity of composting plant, MT/day	Minimum capacity of composting plant, MT/day	Cost of landfilling per ton of waste, including cost of land (Rs./MT)	Operational cost of incinerator (including transportation cost from sorter to incinerator (Rs/MT)	Transportation cost from incinerator to recycling facility, (Rs/MT)	Transportation cost of incinertion ash reject to landfill, (Rs/MT)	Transportation cost of incinertion inorganic reject to landfill, (Rs/MT)	Selling price of compost per ton (Rs/MT waste)	Revenue from recyclable from sorter (Rs/MT)
5000	0	5000	0	5000	5000	0	197.5	689	50	0	0	2500	367.8586
5000	0	5000	0	5000	5000	0	204.14	689	50	0	0	2500	367.8586
5000	0	5000	0	5000	5000	0	193.58	689	50	0	0	2500	367.8586
Items	Recycled percentage	Amount of each item coming out of sorter ICS considering per MT of total waste	Recycling rate, Rs/kg	Recycling revenue per item, Rs/MT of waste									
Paper	5.00	18.60465	9	167.4419									
Rubber & Leather	0.34	1.265116	0.3	0.379535									
Plastic	4.88	18.15814	9	163.4233									
Glass	0.34	1.265116	1	1.265116									
Metal	0.19	0.706977	50	35.34884									
				367.8586									

Table A-6.4 Datasets prepared in Excel for use by LINGO for transfer station near/inside KMC area

Revenue from recyclable from incinerator plant (Rs/MT)	Revenue from recyclable from composting plant (Rs/MT)	Revenue from selling per unit of electricity from W to E incinerator (Rs/kWh)	kWh units of electricity generated from one MT of MSW undergoing incineration
50	50	4.09	170
50	50	4.09	170
50	50	4.09	170

❖ Annexure 6.5

Table A-6.5 Datasets prepared in Excel for use by LINGO for Run 5

DUMPSITE	Recyclable fraction on Intermediate Central Sorting (ICS) feed	Direct dumpable fraction from Intermediate Central Sorting (ICS) feed	Maximum sorted fraction which is fed to incineration plant	Maximum sorted fraction which is fed to composting plant	Recyclable fraction coming out from incinerator pre-sorting	Fraction of incineration inorganic rejects	Fraction of incineration ash reject	Recyclable fraction from presorter to composting	Fraction of inorganic reject from composting	Fraction of process reject from composting	Fraction of composting plant product
D1 (E)	0.0421	0.1053	0.1684	0.6842	0.03125	0.0625	0.0919	0.0192	0.0615	0.1414	0.2657
D2 (N)	0.0421	0.1053	0.1684	0.6842	0.03125	0.0625	0.0919	0.0192	0.0615	0.1414	0.2657
DUMPSITE	Operational cost of sorter in each dumpsite, Rs/MT	Cost of transporting recyclable material from sorter to recycling facilty, Rs/MT	Per ton additional dumping cost from sorter (if incineration or compost not done) Rs/MT		Operational cost of composting facility including transportation cost from ICS to composting plant, Rs/MT	Transportation cost of recyclable materials from composting plant to recycling facilty, Rs/MT	Transportation cost of inorganic reject from composting plant to landfill, Rs/MT	Transportation cost of process reject from composting plant to landfill, Rs/MT			
D1 (E)	100	50	0		269	50	0	0			
D2 (N)	100	50	0		269	50	0	0			

Table A-6.5 Datasets prepared in Excel for use by LINGO for Run 5

Maximum capacity of sorter, MT/day	Minimum capacity of sorter, MT/day	Maximum capacity of incinerator plant, MT/day	Minimum capacity of incinerator plant, MT/day	Maximum capacity of landfill site dumping ground, MT/day	Maximum capacity of composting plant, MT/day	Minimum capacity of composting plant, MT/day	Cost of landfilling per ton of waste, including cost of land (Rs./MT)	Operational cost of incinerator (including transportation cost from sorter to incinerator (Rs/MT)	Transportation cost from incinerator to recycling facility, (Rs/MT)	Transportation cost of incinertion ash reject to landfill, (Rs/MT)	Transportation cost of incinertion inorganic reject to landfill, (Rs/MT)
1900	0	320	0	2200	1300	0	197.5	689	50	0	0
5000	0	5000	0	5000	5000	0	204.14	689	50	0	0
Items	Recycled percentage	Amount of each item coming out of sorter ICS considering per MT of total waste	Recycling rate, Rs/kg	Recycling revenue per item, Rs/MT of waste							
Paper	5.00	18.6046512	9	167.4419							
Rubber & Leather	0.34	1.26511628	0.3	0.379535							
Plastic	4.88	18.1581395	9	163.4233							
Glass	0.34	1.26511628	1	1.265116							
Metal	0.19	0.70697674	50	35.34884							
				367.8586							

Table A-6.5 Datasets prepared in Excel for use by LINGO for Run 5

Selling price of compost per ton (Rs/MT waste)	Revenue from recyclable from sorter (Rs/MT)	Revenue from recyclable from incinerator plant (Rs/MT)	Revenue from recyclable from composting plant (Rs/MT)	Revenue from selling per unit of electricity from W to E incinerator (Rs/kWh)	kWh units of electricity generated from one MT of MSW undergoing incineration
2500	367.8586	50	50	4.09	170
2500	367.8586	50	50	4.09	170

❖ Annexure 6.6 :

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!MATHEMATICAL MODEL FOR SOLID WASTE MANAGEMENT OF KOLKATA;
! E = East Dumpsite, N = North Dumpsite, S = South Dumpsite:    W1 = Silt, W2 = Garbage;

!Objective Function;

MIN = CTRANSP + CINCT + CTCX + CTCS + CTCI + CTCC - CTREVR - CTREVC - CTREVI;


!BS(BB) Silt balance at (bb): Page 38 Equation 3;

SETS:

DUMPSITE/E N S/:
SGF,SR,SDD,SAD,SIF,SCF,IR,IIR,IAR,CR,CIR,CPR,CPD,XF,XSILT,XFG,XFRJ,ICS_RY,ICS_DY,ICS_MAXIN
CI,ICS_MAXCOMP,IP_RY,IP_IRY,IP_AY,CP_RY,CP_IRY,CP_PRY,CP_PRDY,ICS_MAXCAP,ICS_MINCAP,
IP_CAPMAX,IP_CAPMIN,LFCAP,CP_MAXCAP,CP_MINCAP,LFC,IP_OPCST,IP_RC,IP_AC,IP_IRC,IP_REV,
IP,IP_F,CP_PRDC,ICS_RR,IP_RR,CP_RR,ICS_OPCOST,ICS_RC,
ICS_ADC,CP_OPCOST,CP_RC,CP_IRC,CP_PRC,NOOFTRUCKSPERDUMPSITE,NOOFTRIPSPERTRUCK,F
UELCOSTPERTONTRUCKS;
BOROUGH/1..15/:BOROUGH_W1, BOROUGH_W2;
QUANSILTTRANSP(BOROUGH, DUMPSITE):Q_BB_D_HH_S;

ENDSETS

@FOR(BOROUGH(BB): @SUM(DUMPSITE(D):Q_BB_D_HH_S(BB, D))= BOROUGH_W1(BB));

DATA:
 BOROUGH_W1 = @OLE('C:\Sourav\Data with transfer station near\Page 7 Equation 1 and 2', 'BOROUGH_W1');
ENDDATA

!BG(BB) Garbage balance at (bb): Page 38  Equation 2;

SETS:

DEPART_VEHICLE/DD1, DD2, DD3, DD4, DD5, DD6/: NOOFACTVRUNNING, CAPACITY_DD_G, CTC,
CFUEL, CFXDR, CFXDI, DD_FC, DD_NO, DD_IC, CINC, RATE_INC;
QUANGARBAGETRANSP_DD(BOROUGH, DUMPSITE, DEPART_VEHICLE): Q_BB_D_DD_G;
QUANGARBAGETRANSP_HH(BOROUGH, DUMPSITE): Q_BB_D_HH_G;

ENDSETS

@FOR(BOROUGH(BB): @SUM(DUMPSITE(D): @SUM(DEPART_VEHICLE(DD):
        Q_BB_D_DD_G (BB,D,DD)) + Q_BB_D_HH_G(BB,D)) = BOROUGH_W2(BB));

DATA:
  BOROUGH_W2 = @OLE('C:\Sourav\Data with transfer station near\Page 7 Equation 1 and 2', 'BOROUGH_W2');
ENDDATA

!MXG(BB)(DD) and MNG(BB)(DD)  Maximum and minimum despatch of garbage from bb by dd : Page 39
Equations 4 and 5;

SETS:
```

```
FRAC_BOROUGHMAXMIN_DD(BOROUGH,DEPART_VEHICLE): FGBBDDMAX, FGBBDDMIN;

ENDSETS

@FOR(BOROUGH(BB):@FOR(DEPART_VEHICLE(DD):@SUM(DUMPSITE(D):
            Q_BB_D_DD_G(BB,D,DD))<=BOROUGH_W2(BB)*FGBBDDMAX(BB,DD)));

@FOR(BOROUGH(BB): @FOR(DEPART_VEHICLE(DD): @SUM(DUMPSITE(D):
            Q_BB_D_DD_G(BB,D,DD))>= BOROUGH_W2(BB)*FGBBDDMIN(BB,DD)));

DATA:
 FGBBDDMAX, FGBBDDMIN = @OLE('C:\Sourav\Data with transfer station near\Page 7-8 Equation 3-6',
'FGBBDDMAX', 'FGBBDDMIN');
ENDDATA

!MXG(BB)HH and MNG(BB)HH  Maximum and minimum despatch of garbage from bb by hh : Page 39 Equations
5 and 6;

SETS:

 FRAC_BOROUGHMAXMIN_HH(BOROUGH): FGBBHHMAX, FGBBHHMIN;

ENDSETS

@FOR(BOROUGH(BB):
     @SUM(DUMPSITE(D):Q_BB_D_HH_G(BB,D))<= BOROUGH_W2(BB)*FGBBHHMAX(BB));

@FOR(BOROUGH(BB):
     @SUM(DUMPSITE(D):Q_BB_D_HH_G(BB,D))>= BOROUGH_W2(BB)*FGBBHHMIN(BB));

DATA:
 FGBBHHMAX, FGBBHHMIN = @OLE('C:\Sourav\Data with transfer station near\Page 7-8 Equation 3-6',
'FGBBHHMAX', 'FGBBHHMIN');
ENDDATA

!MXT(DD)(D)(Z)  Maximum trips of dd in zone z of d : Page 44 Euation 36;

SETS:

ZONE/1..2/;
ACTNOOFTRIPSOF_DD_IN_Z_OF_D(DEPART_VEHICLE,DUMPSITE,ZONE):AT_DD_D_Z;
MAXOFDDFROMZONE1OR2OF_D(DEPART_VEHICLE,ZONE):MAXTRIPS;

ENDSETS

@FOR(DEPART_VEHICLE(DD):@FOR(DUMPSITE(D):@FOR(ZONE(Z):
        AT_DD_D_Z(DD,D,Z)<=NOOFACTVRUNNING(DD)* MAXTRIPS(DD,Z))));

DATA:
  NOOFACTVRUNNING, MAXTRIPS = @OLE('C:\Sourav\Data with transfer station near\Page 16 Equation 32-
33A', 'NOOFACTVRUNNING','MAXTRIPS');
ENDDATA

!MXT(DD) Maximum possible trip limit by dd in all zone z, all d  :  Page 44 Equation 37;
!MNT(DD) Minimum possible trip limit by dd in all zone z, all d  :  Page 44 Equation 38;
```

```
SETS:

MAXMAXTRIPSBYDD_1_OR_2(DEPART_VEHICLE):MAXMAXTRIPS1OR2;
MINMINTRIPSBYDD_1_OR_2(DEPART_VEHICLE):MINMINTRIPS1OR2;

ENDSETS

@FOR(DEPART_VEHICLE(DD): @SUM(DUMPSITE(D): @SUM(ZONE(Z):
        AT_DD_D_Z(DD,D,Z)))<= NOOFACTVRUNNING(DD)* MAXMAXTRIPS1OR2(DD));

@FOR(DEPART_VEHICLE(DD): @SUM(DUMPSITE(D): @SUM(ZONE(Z):
        AT_DD_D_Z(DD,D,Z)))>= NOOFACTVRUNNING(DD)* MINMINTRIPS1OR2(DD));

DATA:
 MAXMAXTRIPS1OR2,MINMINTRIPS1OR2 = @OLE('C:\Sourav\Data with transfer station near\Page 16
Equation 32-33A', 'MAXMAXTRIPS1OR2', 'MINMINTRIPS1OR2');
ENDDATA

! DG(HH)(D)(Z);

SETS:

BBINDUMP_E_ZONE_1(BOROUGH)/@OLE('C:\Sourav\Data with transfer station near\Page 17 Equation
35','BB_E_1')/;
BBINDUMP_E_ZONE_2(BOROUGH)/@OLE('C:\Sourav\Data with transfer station near\Page 17 Equation
35','BB_E_2')/;
BBINDUMP_N_ZONE_1(BOROUGH)/@OLE('C:\Sourav\Data with transfer station near\Page 17 Equation
35','BB_N_1')/;
BBINDUMP_N_ZONE_2(BOROUGH)/@OLE('C:\Sourav\Data with transfer station near\Page 17 Equation
35','BB_N_2')/;
BBINDUMP_S_ZONE_1(BOROUGH)/@OLE('C:\Sourav\Data with transfer station near\Page 17 Equation
35','BB_S_1')/;
BBINDUMP_S_ZONE_2(BOROUGH)/@OLE('C:\Sourav\Data with transfer station near\Page 17 Equation
35','BB_S_2')/;
QUANGARBAGE_HH_TO_D_FROM_Z(DUMPSITE, ZONE): DGHH;

ENDSETS

  DGHH(E,1)= @SUM(BBINDUMP_E_ZONE_1(BB):Q_BB_D_HH_G(BB,E));
  DGHH(E,2)= @SUM(BBINDUMP_E_ZONE_2(BB):Q_BB_D_HH_G(BB,E));
  DGHH(N,1)= @SUM(BBINDUMP_N_ZONE_1(BB):Q_BB_D_HH_G(BB,N));
  DGHH(N,2)= @SUM(BBINDUMP_N_ZONE_2(BB):Q_BB_D_HH_G(BB,N));
  DGHH(S,1)= @SUM(BBINDUMP_S_ZONE_1(BB):Q_BB_D_HH_G(BB,S));
  DGHH(S,2)= @SUM(BBINDUMP_S_ZONE_2(BB):Q_BB_D_HH_G(BB,S));

!  DG(DD)(D)(Z) Amount of garbage taken by dd type vehicle to d from z (of d) ;

SETS:

  QUANGARBAGE_DD_TO_D_FROM_Z(DEPART_VEHICLE,DUMPSITE, ZONE): DGDD;

ENDSETS

@FOR(DEPART_VEHICLE(DD):
@SUM(BBINDUMP_E_ZONE_1(BB):Q_BB_D_DD_G(BB,E,DD)) = DGDD(DD,E,1));
```

```
@FOR(DEPART_VEHICLE(DD):
@SUM(BBINDUMP_E_ZONE_2(BB):Q_BB_D_DD_G(BB,E,DD)) = DGDD(DD,E,2));

  @FOR(DEPART_VEHICLE(DD):
  @SUM(BBINDUMP_N_ZONE_1(BB):Q_BB_D_DD_G(BB,N,DD)) = DGDD(DD,N,1));

  @FOR(DEPART_VEHICLE(DD):
  @SUM(BBINDUMP_N_ZONE_2(BB):Q_BB_D_DD_G(BB,N,DD)) = DGDD(DD,N,2));

  @FOR(DEPART_VEHICLE(DD):
  @SUM(BBINDUMP_S_ZONE_1(BB):Q_BB_D_DD_G(BB,S,DD)) = DGDD(DD,S,1));

  @FOR(DEPART_VEHICLE(DD):
  @SUM(BBINDUMP_S_ZONE_2(BB):Q_BB_D_DD_G(BB,S,DD)) = DGDD(DD,S,2));

! DS HH(D)(Z) Amount of silt by hh to d from z (of d) : Page 18 Equation 36;

SETS:
QUANSILT_HH_TO_D_FROM_Z(DUMPSITE, ZONE): DSHH;
ENDSETS

  DSHH(E,1)= @SUM(BBINDUMP_E_ZONE_1(BB):Q_BB_D_HH_S(BB,E));
  DSHH(E,2)= @SUM(BBINDUMP_E_ZONE_2(BB):Q_BB_D_HH_S(BB,E));
  DSHH(N,1)= @SUM(BBINDUMP_N_ZONE_1(BB):Q_BB_D_HH_S(BB,N));
  DSHH(N,2)= @SUM(BBINDUMP_N_ZONE_2(BB):Q_BB_D_HH_S(BB,N));
  DSHH(S,1)= @SUM(BBINDUMP_S_ZONE_1(BB):Q_BB_D_HH_S(BB,S));
  DSHH(S,2)= @SUM(BBINDUMP_S_ZONE_2(BB):Q_BB_D_HH_S(BB,S));


! AT(DD)(D)(Z) Actual number of trips by dd in zone z of d ;

@FOR(DEPART_VEHICLE(DD):@SUM(BBINDUMP_E_ZONE_1(BB):
Q_BB_D_DD_G(BB,E,DD))=AT_DD_D_Z(DD,E,1)*CAPACITY_DD_G(DD));

@FOR(DEPART_VEHICLE(DD):@SUM(BBINDUMP_E_ZONE_2(BB):
Q_BB_D_DD_G(BB,E,DD)) = AT_DD_D_Z(DD,E,2)*CAPACITY_DD_G(DD));

@FOR(DEPART_VEHICLE(DD):@SUM(BBINDUMP_N_ZONE_1(BB):
Q_BB_D_DD_G(BB,N,DD)) = AT_DD_D_Z(DD,N,1)*CAPACITY_DD_G(DD));

@FOR(DEPART_VEHICLE(DD):@SUM(BBINDUMP_N_ZONE_2(BB):
Q_BB_D_DD_G(BB,N,DD)) = AT_DD_D_Z(DD,N,2)*CAPACITY_DD_G(DD));

@FOR(DEPART_VEHICLE(DD):@SUM(BBINDUMP_S_ZONE_1(BB):
Q_BB_D_DD_G(BB,S,DD)) = AT_DD_D_Z(DD,S,1)*CAPACITY_DD_G(DD));

@FOR(DEPART_VEHICLE(DD):@SUM(BBINDUMP_S_ZONE_2(BB):
Q_BB_D_DD_G(BB,S,DD)) = AT_DD_D_Z(DD,S,2)*CAPACITY_DD_G(DD));

DATA:
CAPACITY_DD_G = @OLE('C:\Sourav\Data with transfer station near\Page 16 Equation 32-
33A','CAPACITY_DD_G');
ENDDATA

! ATHHG(D)(Z), ATHHS(D)(Z) Actual number of trips by hh for garbage, silt in zone z of d ;
```

```
SETS:
ACTNOOFTRIPSOF_HH_IN_Z_OF_D (DUMPSITE, ZONE): AT_HHG_D_Z, AT_HHS_D_Z;

ENDSETS

 @SUM(BBINDUMP_E_ZONE_1(BB):Q_BB_D_HH_G(BB,E))=AT_HHG_D_Z(E,1)*CAPACITY_HH_G;
  @SUM(BBINDUMP_E_ZONE_2(BB):Q_BB_D_HH_G(BB,E))= AT_HHG_D_Z(E,2)*CAPACITY_HH_G;
  @SUM(BBINDUMP_N_ZONE_1(BB):Q_BB_D_HH_G(BB,N))= AT_HHG_D_Z(N,1)*CAPACITY_HH_G;
  @SUM(BBINDUMP_N_ZONE_2(BB):Q_BB_D_HH_G(BB,N))= AT_HHG_D_Z(N,2)*CAPACITY_HH_G;
  @SUM(BBINDUMP_S_ZONE_1(BB):Q_BB_D_HH_G(BB,S))= AT_HHG_D_Z(S,1)*CAPACITY_HH_G;
  @SUM(BBINDUMP_S_ZONE_2(BB):Q_BB_D_HH_G(BB,S))= AT_HHG_D_Z(S,2)*CAPACITY_HH_G;

  @SUM(BBINDUMP_E_ZONE_1(BB):Q_BB_D_HH_S(BB,E))= AT_HHS_D_Z(E,1)*CAPACITY_HH_S;
  @SUM(BBINDUMP_E_ZONE_2(BB):Q_BB_D_HH_S(BB,E))= AT_HHS_D_Z(E,2)*CAPACITY_HH_S;
  @SUM(BBINDUMP_N_ZONE_1(BB):Q_BB_D_HH_S(BB,N))= AT_HHS_D_Z(N,1)*CAPACITY_HH_S;
  @SUM(BBINDUMP_N_ZONE_2(BB):Q_BB_D_HH_S(BB,N))= AT_HHS_D_Z(N,2)*CAPACITY_HH_S;
  @SUM(BBINDUMP_S_ZONE_1(BB):Q_BB_D_HH_S(BB,S))= AT_HHS_D_Z(S,1)*CAPACITY_HH_S;
  @SUM(BBINDUMP_S_ZONE_2(BB):Q_BB_D_HH_S(BB,S))= AT_HHS_D_Z(S,2)*CAPACITY_HH_S;

DATA:
  CAPACITY_HH_G, CAPACITY_HH_S = @OLE('C:\Sourav\Data with transfer station near\Page 16 Equation 32-
33A','CAPACITY_HH_G','CAPACITY_HH_S');
ENDDATA

!  SGF(D)  Totalling feed to sorter at d ;

 @FOR(DUMPSITE(D):@SUM(BOROUGH(BB):
  @SUM(DEPART_VEHICLE(DD):Q_BB_D_DD_G(BB,D,DD))+ Q_BB_D_HH_G(BB,D))= SGF(D));

!  BSGF(D)  Balance for sorter ;

 @FOR(DUMPSITE(D):SGF(D) = SR(D)+ SDD(D)+ SAD(D)+ SIF(D)+ SCF(D));

! MXSR(D) Maximum amount  recyclable from sorter at dumpsite d ;

 @FOR(DUMPSITE(D):SR(D) - SGF(D)* ICS_RY(D) <= 0);

  DATA:
   ICS_RY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','ICS_RY');
  ENDDATA

! MXSDD(D)  Maximum sorted amount which is direct dumpable at d ;

 @FOR(DUMPSITE(D):SDD(D) - SGF(D)* ICS_DDY(D) <= 0);

 DATA:
  ICS_DDY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','ICS_DDY');
 ENDDATA

! MXSIF(D)  Maximum sorted amount which is fed to incineration plant at d ;

 @FOR(DUMPSITE(D):SIF(D) - SGF(D)* ICS_MAXINCI(D) <= 0);

 DATA:
  ICS_MAXINCI = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','ICS_MAXINCI');
 ENDDATA
```

```
! MXSCF(D)  Maximum sorted amount which is fed to composting plant at d ;

 @FOR(DUMPSITE(D):SCF(D) - SGF(D)* ICS_MAXCOMP(D) <= 0);

 DATA:
   ICS_MAXCOMP = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-
30','ICS_MAXCOMP');
 ENDDATA

! BIR(D)  Balance of incineration recyclable at dumpsite d ;

 @FOR(DUMPSITE(D):IR(D) - SIF(D)* IP_RY(D) = 0);

 DATA:
   IP_RY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_RY');
 ENDDATA

! BIIR(D)  Balance of incineration inorganic rejects at dumpsite d ;

 @FOR(DUMPSITE(D):IIR(D) - SIF(D)* IP_IRY(D) = 0);

 DATA:
   IP_IRY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_IRY');
 ENDDATA

! BIAR(D)  Balance of incineration ash rejects at dumpsite d ;

 @FOR(DUMPSITE(D):IAR(D) - SIF(D)* IP_AY(D) = 0);

 DATA:
    IP_AY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_AY');
 ENDDATA

! BIP(D)  Balance of electricity/power generated from incinerator at dumpsite d;

 @FOR(DUMPSITE(D): IP(D) - SIF(D)* IP_F(D) = 0);

 DATA:
   IP_F = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_F');
 ENDDATA

! BCR(D)  Balance of compost plant recycle at dumpsite d ;

 @FOR(DUMPSITE(D):CR(D) - SCF(D)* CP_RY(D) = 0);

 DATA:
   CP_RY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_RY');
 ENDDATA

! BCIR(D)  Balance of compost plant inorganic rejects at dumpsite d ;

 @FOR(DUMPSITE(D):CIR(D) - SCF(D)* CP_IRY(D) = 0);
```

```
 DATA:
  CP_IRY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_IRY');
 ENDDATA
! BCPR(D)  Balance of compost plant process rejects at dumpsite d ;

 @FOR(DUMPSITE(D):CPR(D) - SCF(D)* CP_PRY(D) = 0);

 DATA:
  CP_PRY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_PRY');
 ENDDATA

! BCPD(D)  Balance of compost plant product at dumpsite d ;

 @FOR(DUMPSITE(D):CPD(D) - SCF(D)* CP_PRDY(D) = 0);

 DATA:
  CP_PRDY = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_PRDY');
 ENDDATA

! XF(D)  Totalling landfill amount at dumpsite d ;

 @FOR(DUMPSITE(D):XF(D) - XSILT(D) - XFG(D) - XFRJ(D)= 0);

! BXS(D)  Balance of silt at landfill d ;

 @FOR(DUMPSITE(D):@SUM(BOROUGH(BB):Q_BB_D_HH_S(BB,D))= XSILT(D));

! BXFG(D)  Balance of direct dumpable + addl dumpable at landfill d ;

 @FOR(DUMPSITE(D):XFG(D) = SDD(D)+SAD(D));

! BXFRJ(D)  Totalling of all rejects at dumpsite d ;

 @FOR(DUMPSITE(D):XFRJ(D) = IIR(D)+CIR(D)+IAR(D)+CPR(D));

! SCAPX(D)  Maximum capacity of sorter at dumpsite d ;

  @FOR(DUMPSITE(D):SGF(D) <= ICS_MAXCAP(D));

  DATA:
  ICS_MAXCAP = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','ICS_MAXCAP');
 ENDDATA

! SCAPN(D)  Minimum capacity of sorter at dumpsite d ;

  @FOR(DUMPSITE(D):SGF(D) >= ICS_MINCAP(D));

  DATA:
  ICS_MINCAP = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','ICS_MINCAP');
 ENDDATA

! ICAPX(D)  Maximum capacity of incinerator plant at dumpsite d ;

  @FOR(DUMPSITE(D): SIF(D) <= IP_CAPMAX(D));

  DATA:
```

```
  IP_CAPMAX = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_CAPMAX');
 ENDDATA

! ICAPN(D)  Minimum capacity of incinerator plant at dumpsite d ;

  @FOR(DUMPSITE(D):SIF(D) >= IP_CAPMIN(D));

   DATA:
  IP_CAPMIN = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_CAPMIN');
 ENDDATA

!XCAPX(D) Maximum capacity of landfill at dumpsite d ;

 @FOR(DUMPSITE(D):XF(D) <= LFCAP(D));

  DATA:
  LFCAP = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','LFCAP');
 ENDDATA

! CCAPX(D)  Maximum capacity of composting plant at dumpsite d ;

  @FOR(DUMPSITE(D): SCF(D) <= CP_MAXCAP(D));

 DATA:
  CP_MAXCAP = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_MAXCAP');
 ENDDATA

! CCAPN(D)  Minimum capacity of composting plant at dumpsite d ;

  @FOR(DUMPSITE(D): SCF(D) >= CP_MINCAP(D));

  DATA:
  CP_MINCAP = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_MINCAP');
 ENDDATA

! CTCX Total cost of landfilling ;

  @SUM(DUMPSITE(D):(XF(D)*LFC(D)))= CTCX;

 DATA:
  LFC = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','LFC');
 ENDDATA

! CTCS Total sorting cost ;

  CTCS  =  @SUM(DUMPSITE(D):(SGF(D)*ICS_OPCOST(D)))+  @SUM(DUMPSITE(D):(SR(D)*ICS_RC(D)+
SAD(D)*ICS_ADC(D)));

 DATA:
  ICS_OPCOST,ICS_RC, ICS_ADC = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-
30','ICS_OPCOST','ICS_RC','ICS_ADC');
 ENDDATA

! CTCI Total cost of incineration ;
```

```
 @SUM(DUMPSITE(D):(SIF(D)*IP_OPCOST(D)+IR(D)*IP_RC(D)+IAR(D)*IP_AC(D)+IIR(D)*IP_IRC(D)))=
CTCI;

 DATA:
  IP_OPCOST,IP_RC,IP_AC,IP_IRC = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-
30','IP_OPCOST','IP_RC','IP_AC','IP_IRC');
 ENDDATA

! CTCC Total cost of composting ;

 @SUM(DUMPSITE(D):(SCF(D)*CP_OPCOST(D)+        CR(D)*CP_RC(D)+        CIR(D)*CP_IRC(D)+
CPR(D)*CP_PRC(D)))= CTCC;

 DATA:
  CP_OPCOST,CP_RC,CP_IRC,CP_PRC = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-
30','CP_OPCOST','CP_RC','CP_IRC','CP_PRC');
 ENDDATA

! CTREVC Total revenue from compost ;

 @SUM(DUMPSITE(D):(CPD(D)*CP_PRDC(D)))= CTREVC;

 DATA:
  CP_PRDC = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','CP_PRDC');
 ENDDATA

! CTREVI Total revenue from incinerator ;

 @SUM(DUMPSITE(D):(IP(D)*IP_REV(D)))= CTREVI;

 DATA:
  IP_REV = @OLE('C:\Sourav\Data with transfer station near\Page 9-15 Equation 9-30','IP_REV');
 ENDDATA

! CTREVR Total revenue from recyclable ;

 @SUM(DUMPSITE(D):(SR(D)*ICS_RR(D)+IR(D)*IP_RR(D)+ CR(D)*CP_RR(D)))= CTREVR;

 DATA:
  ICS_RR,IP_RR,CP_RR  =  @OLE('C:\Sourav\Data  with  transfer  station  near\Page  9-15  Equation  9-
30','ICS_RR','IP_RR','CP_RR');
 ENDDATA

! CTRANSP Total transportation cost ;

 CTRANSP = CTCHH + @SUM(DEPART_VEHICLE(DD): CTC(DD))+ CTCTRUCKS;

! CTCHH Total cost of transportation by HH ;

 CTCHH = CTCGHH + CTCSHH;

! CTCGHH Cost of garbage transport by HH ;

 SETS:
   PERTONTRANSCOST_HH_BB_TO_D_G(BOROUGH, DUMPSITE): BB_HCG;
 ENDSETS
```

```
 @SUM(BOROUGH(BB):@SUM(DUMPSITE(D):Q_BB_D_HH_G(BB,D)*BB_HCG(BB,D))) = CTCGHH;


DATA:
  BB_HCG = @OLE('C:\Sourav\Data with transfer station near\Page 4 Equation 9-10','BB_HCG');
 ENDDATA

! CTCSHH Cost of silt transport by HH ;

 SETS:
  PERTONTRANSCOST_HH_BB_TO_D_S(BOROUGH, DUMPSITE): BB_HCS;
 ENDSETS

 @SUM(BOROUGH(BB):@SUM(DUMPSITE(D):Q_BB_D_HH_S(BB,D)*BB_HCS(BB,D))) = CTCSHH;

 DATA:
  BB_HCS = @OLE('C:\Sourav\Data with transfer station near\Page 4 Equation 9-10','BB_HCS');
 ENDDATA

! CTC(DD) Cost of transportation by departmental vehicles ;

  @FOR(DEPART_VEHICLE(DD):CTC(DD)= CFUEL(DD)+ CFXDR(DD) + CFXDI(DD));

! CFUEL(DD) Cost of fuel per ton of garbage transportation for departmental vehicles ;

 SETS:

  PERTONFUELCOST_BB_D_G(BOROUGH,   DUMPSITE):   BB_FC_DD1,   BB_FC_DD2,   BB_FC_DD3,
BB_FC_DD4, BB_FC_DD5, BB_FC_DD6;
  QUANGARBAGETRANSP_BB_D(BOROUGH,    DUMPSITE):    Q_BB_D_DD1_G,    Q_BB_D_DD2_G,
Q_BB_D_DD3_G, Q_BB_D_DD4_G, Q_BB_D_DD5_G, Q_BB_D_DD6_G;

 ENDSETS

 @FOR(BOROUGH(BB):@FOR(DUMPSITE(D):Q_BB_D_DD_G(BB,D,DD1)= Q_BB_D_DD1_G(BB,D)));

 @FOR(BOROUGH(BB):@FOR(DUMPSITE(D):Q_BB_D_DD_G(BB,D,DD2)= Q_BB_D_DD2_G(BB,D)));

 @FOR(BOROUGH(BB):@FOR(DUMPSITE(D):Q_BB_D_DD_G(BB,D,DD3)= Q_BB_D_DD3_G(BB,D)));

 @FOR(BOROUGH(BB):@FOR(DUMPSITE(D):Q_BB_D_DD_G(BB,D,DD4)= Q_BB_D_DD4_G(BB,D)));

 @FOR(BOROUGH(BB):@FOR(DUMPSITE(D):Q_BB_D_DD_G(BB,D,DD5)= Q_BB_D_DD5_G(BB,D)));

 @FOR(BOROUGH(BB):@FOR(DUMPSITE(D):Q_BB_D_DD_G(BB,D,DD6)= Q_BB_D_DD6_G(BB,D)));

@SUM(BOROUGH(BB):
@SUM(DUMPSITE(D):Q_BB_D_DD1_G(BB,D)*BB_FC_DD1(BB,D)))= CFUEL(DD1);

 @SUM(BOROUGH(BB):
@SUM(DUMPSITE(D):Q_BB_D_DD2_G(BB,D)*BB_FC_DD2(BB,D)))= CFUEL(DD2);

 @SUM(BOROUGH(BB):
  @SUM(DUMPSITE(D):Q_BB_D_DD3_G(BB,D)*BB_FC_DD3(BB,D)))= CFUEL(DD3);
```

```
 @SUM(BOROUGH(BB):
  @SUM(DUMPSITE(D):Q_BB_D_DD4_G(BB,D)*BB_FC_DD4(BB,D)))= CFUEL(DD4);


 @SUM(BOROUGH(BB):
  @SUM(DUMPSITE(D):Q_BB_D_DD5_G(BB,D)*BB_FC_DD5(BB,D)))= CFUEL(DD5);

 @SUM(BOROUGH(BB):
  @SUM(DUMPSITE(D):Q_BB_D_DD6_G(BB,D)*BB_FC_DD6(BB,D)))= CFUEL(DD6);

 DATA:
     BB_FC_DD1 = @OLE('C:\Sourav\Data with transfer station near\Page 5 Equation 12A','BB_FC_DD1');
     BB_FC_DD2 = @OLE('C:\Sourav\Data with transfer station near\Page 5 Equation 12B','BB_FC_DD2');
     BB_FC_DD3 = @OLE('C:\Sourav\Data with transfer station near\Page 5 Equation 12C','BB_FC_DD3');
     BB_FC_DD4 = @OLE('C:\Sourav\Data with transfer station near\Page 5 Equation 12D','BB_FC_DD4');
     BB_FC_DD5 = @OLE('C:\Sourav\Data with transfer station near\Page 5 Equation 12E','BB_FC_DD5');
     BB_FC_DD6 = @OLE('C:\Sourav\Data with transfer station near\Page 5 Equation 12F','BB_FC_DD6');

 ENDDATA

! CFXDR(DD) Fixed cost of running dd type vehicles ;

  @FOR(DEPART_VEHICLE(DD):CFXDR(DD)= NOOFACTVRUNNING(DD)*DD_FC(DD));

  DATA:
    DD_FC = @OLE('C:\Sourav\Data with transfer station near\Page 5-6 Equation 13-14','DD_FC');
  ENDDATA

! CFXDI(DD) Fixed cost of idle dd type vehicles ;

  @FOR(DEPART_VEHICLE(DD):CFXDI(DD)= (DD_NO(DD) - NOOFACTVRUNNING(DD))*DD_IC(DD));

  DATA:
    DD_IC = @OLE('C:\Sourav\Data with transfer station near\Page 5-6 Equation 13-14','DD_IC');
    DD_NO = @OLE('C:\Sourav\Data with transfer station near\Page 16 Equation 32-33A','DD_NO');
  ENDDATA

! CINCT Incentive cost ;

@FOR(DEPART_VEHICLE(DD):@SUM(DUMPSITE(D):@SUM(ZONE(Z):
DGDD(DD,D,Z)))*RATE_INC(DD)=CINC(DD)+NOOFACTVRUNNING(DD)*MINMINTRIPS1OR2(DD)*CAP
ACITY_DD_G(DD)*RATE_INC(DD));

CINCT = @SUM(DEPART_VEHICLE(DD):CINC(DD));

  DATA:
    RATE_INC = @OLE('C:\Sourav\Data with transfer station near\Page 16 Equation 32-33A','RATE_INC');
  ENDDATA


! CTCTRUCKS: Cost of transporting waste from transfer station to landfill/dumpsite by heavy duty trucks;

  CTCTRUCKS = CFUELTRUCKSTOTAL + CFXDRTRUCKSTOTAL + CFXDITRUCKSTOTAL;

  CFUELTRUCKSTOTAL = @SUM(DUMPSITE(D): XF(D)*FUELCOSTPERTONTRUCKS(D));
```

```
 CFXDRTRUCKSTOTAL = TRUCKS_NA * TRUCKS_RC;

 CFXDITRUCKSTOTAL = (TRUCKS_NO - TRUCKS_NA)*TRUCKS_IC;

 DATA:
   FUELCOSTPERTONTRUCKS, TRUCKS_NO, TRUCKS_NA, TRUCKS_RC,TRUCKS_IC =
@OLE('C:\Sourav\Data with transfer station near\Heavy Duty Truck','FUELCOSTPERTONTRUCKS',
'TRUCKS_NO', 'TRUCKS_NA', 'TRUCKS_RC', 'TRUCKS_IC');
 ENDDATA

! Restricting additional dumping to zero;

 @FOR(DUMPSITE(D):SAD(D) = 0);

! Equating number of trucktrips with dumpable waste;

 @FOR(DUMPSITE(D):@GIN(NOOFTRUCKSPERDUMPSITE));

 @FOR(DUMPSITE(D):XF(D)<= NOOFTRIPSPERTRUCK(D)*NOOFTRUCKSPERDUMPSITE(D)*20);

 @SUM(DUMPSITE(D):NOOFTRUCKSPERDUMPSITE(D))= TRUCKS_NA;

 DATA:
   NOOFTRIPSPERTRUCK = @OLE('C:\Sourav\Data with transfer station near\Heavy Duty
Truck','NOOFTRIPSPERTRUCK');
 ENDDATA
```

❖ Annexure 6.7 :

```
MODEL:
[_1] MIN= CTRANSP + CINCT + CTCX + CTCS + CTCI + CTCC - CTREVR – CTREVC -CTREVI;
   [_2] Q_BB_D_HH_S_1_E + Q_BB_D_HH_S_1_N + Q_BB_D_HH_S_1_S = 21.11 ;
   [_3] Q_BB_D_HH_S_2_E + Q_BB_D_HH_S_2_N + Q_BB_D_HH_S_2_S = 12.63 ;
   [_4] Q_BB_D_HH_S_3_E + Q_BB_D_HH_S_3_N + Q_BB_D_HH_S_3_S = 21.09 ;
   [_5] Q_BB_D_HH_S_4_E + Q_BB_D_HH_S_4_N + Q_BB_D_HH_S_4_S = 13.35 ;
   [_6] Q_BB_D_HH_S_5_E + Q_BB_D_HH_S_5_N + Q_BB_D_HH_S_5_S = 18 ;
   [_7] Q_BB_D_HH_S_6_E + Q_BB_D_HH_S_6_N + Q_BB_D_HH_S_6_S = 36.9 ;
   [_8] Q_BB_D_HH_S_7_E + Q_BB_D_HH_S_7_N + Q_BB_D_HH_S_7_S = 65.7 ;
   [_9] Q_BB_D_HH_S_8_E + Q_BB_D_HH_S_8_N + Q_BB_D_HH_S_8_S = 42.08 ;
   [_10] Q_BB_D_HH_S_9_E + Q_BB_D_HH_S_9_N + Q_BB_D_HH_S_9_S = 27.2 ;
   [_11] Q_BB_D_HH_S_10_E + Q_BB_D_HH_S_10_N + Q_BB_D_HH_S_10_S = 32.5 ;
   [_12] Q_BB_D_HH_S_11_E + Q_BB_D_HH_S_11_N + Q_BB_D_HH_S_11_S = 1.89 ;
   [_13] Q_BB_D_HH_S_12_E + Q_BB_D_HH_S_12_N + Q_BB_D_HH_S_12_S = 2.36 ;
   [_14] Q_BB_D_HH_S_13_E + Q_BB_D_HH_S_13_N + Q_BB_D_HH_S_13_S = 4.14 ;
   [_15] Q_BB_D_HH_S_14_E + Q_BB_D_HH_S_14_N + Q_BB_D_HH_S_14_S = 9.84 ;
   [_16] Q_BB_D_HH_S_15_E + Q_BB_D_HH_S_15_N + Q_BB_D_HH_S_15_S = 0.06 ;
   [_17] Q_BB_D_HH_G_1_E + Q_BB_D_HH_G_1_N + Q_BB_D_HH_G_1_S +
   Q_BB_D_DD_G_1_E_DD1 + Q_BB_D_DD_G_1_E_DD2 + Q_BB_D_DD_G_1_E_DD3 +
   Q_BB_D_DD_G_1_E_DD4 + Q_BB_D_DD_G_1_E_DD5 + Q_BB_D_DD_G_1_E_DD6 +
   Q_BB_D_DD_G_1_N_DD1 + Q_BB_D_DD_G_1_N_DD2 + Q_BB_D_DD_G_1_N_DD3 +
   Q_BB_D_DD_G_1_N_DD4 + Q_BB_D_DD_G_1_N_DD5 + Q_BB_D_DD_G_1_N_DD6 +
   Q_BB_D_DD_G_1_S_DD1 + Q_BB_D_DD_G_1_S_DD2 + Q_BB_D_DD_G_1_S_DD3 +
   Q_BB_D_DD_G_1_S_DD4 + Q_BB_D_DD_G_1_S_DD5 + Q_BB_D_DD_G_1_S_DD6 = 196.28;
  [_18] Q_BB_D_HH_G_2_E + Q_BB_D_HH_G_2_N + Q_BB_D_HH_G_2_S +
   Q_BB_D_DD_G_2_E_DD1 + Q_BB_D_DD_G_2_E_DD2 + Q_BB_D_DD_G_2_E_DD3 +
   Q_BB_D_DD_G_2_E_DD4 + Q_BB_D_DD_G_2_E_DD5 + Q_BB_D_DD_G_2_E_DD6 +
   Q_BB_D_DD_G_2_N_DD1 + Q_BB_D_DD_G_2_N_DD2 + Q_BB_D_DD_G_2_N_DD3 +
   Q_BB_D_DD_G_2_N_DD4 + Q_BB_D_DD_G_2_N_DD5 + Q_BB_D_DD_G_2_N_DD6 +
   Q_BB_D_DD_G_2_S_DD1 + Q_BB_D_DD_G_2_S_DD2 + Q_BB_D_DD_G_2_S_DD3 +
   Q_BB_D_DD_G_2_S_DD4 + Q_BB_D_DD_G_2_S_DD5 + Q_BB_D_DD_G_2_S_DD6 = 192.63;
   [_19] Q_BB_D_HH_G_3_E + Q_BB_D_HH_G_3_N + Q_BB_D_HH_G_3_S +
   Q_BB_D_DD_G_3_E_DD1 + Q_BB_D_DD_G_3_E_DD2 + Q_BB_D_DD_G_3_E_DD3 +
   Q_BB_D_DD_G_3_E_DD4 + Q_BB_D_DD_G_3_E_DD5 + Q_BB_D_DD_G_3_E_DD6 +
   Q_BB_D_DD_G_3_N_DD1 + Q_BB_D_DD_G_3_N_DD2 + Q_BB_D_DD_G_3_N_DD3 +
   Q_BB_D_DD_G_3_N_DD4 + Q_BB_D_DD_G_3_N_DD5 + Q_BB_D_DD_G_3_N_DD6 +
   Q_BB_D_DD_G_3_S_DD1 + Q_BB_D_DD_G_3_S_DD2 + Q_BB_D_DD_G_3_S_DD3 +
   Q_BB_D_DD_G_3_S_DD4 + Q_BB_D_DD_G_3_S_DD5 + Q_BB_D_DD_G_3_S_DD6 = 197.43;
   [_20] Q_BB_D_HH_G_4_E + Q_BB_D_HH_G_4_N + Q_BB_D_HH_G_4_S +
   Q_BB_D_DD_G_4_E_DD1 + Q_BB_D_DD_G_4_E_DD2 + Q_BB_D_DD_G_4_E_DD3 +
   Q_BB_D_DD_G_4_E_DD4 + Q_BB_D_DD_G_4_E_DD5 + Q_BB_D_DD_G_4_E_DD6 +
   Q_BB_D_DD_G_4_N_DD1 + Q_BB_D_DD_G_4_N_DD2 + Q_BB_D_DD_G_4_N_DD3 +
   Q_BB_D_DD_G_4_N_DD4 + Q_BB_D_DD_G_4_N_DD5 + Q_BB_D_DD_G_4_N_DD6 +
   Q_BB_D_DD_G_4_S_DD1 + Q_BB_D_DD_G_4_S_DD2 + Q_BB_D_DD_G_4_S_DD3 +
   Q_BB_D_DD_G_4_S_DD4 + Q_BB_D_DD_G_4_S_DD5 + Q_BB_D_DD_G_4_S_DD6 = 171.85;
   [_21] Q_BB_D_HH_G_5_E + Q_BB_D_HH_G_5_N + Q_BB_D_HH_G_5_S +
   Q_BB_D_DD_G_5_E_DD1 + Q_BB_D_DD_G_5_E_DD2 + Q_BB_D_DD_G_5_E_DD3 +
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    Q_BB_D_DD_G_5_E_DD4 + Q_BB_D_DD_G_5_E_DD5 + Q_BB_D_DD_G_5_E_DD6 +
    Q_BB_D_DD_G_5_N_DD1 + Q_BB_D_DD_G_5_N_DD2 + Q_BB_D_DD_G_5_N_DD3 +
    Q_BB_D_DD_G_5_N_DD4 + Q_BB_D_DD_G_5_N_DD5 + Q_BB_D_DD_G_5_N_DD6 +
    Q_BB_D_DD_G_5_S_DD1 + Q_BB_D_DD_G_5_S_DD2 + Q_BB_D_DD_G_5_S_DD3 +
    Q_BB_D_DD_G_5_S_DD4 + Q_BB_D_DD_G_5_S_DD5 + Q_BB_D_DD_G_5_S_DD6 = 207.33;
    [_22] Q_BB_D_HH_G_6_E + Q_BB_D_HH_G_6_N + Q_BB_D_HH_G_6_S +
    Q_BB_D_DD_G_6_E_DD1 + Q_BB_D_DD_G_6_E_DD2 + Q_BB_D_DD_G_6_E_DD3 +
    Q_BB_D_DD_G_6_E_DD4 + Q_BB_D_DD_G_6_E_DD5 + Q_BB_D_DD_G_6_E_DD6 +
    Q_BB_D_DD_G_6_N_DD1 + Q_BB_D_DD_G_6_N_DD2 + Q_BB_D_DD_G_6_N_DD3 +
    Q_BB_D_DD_G_6_N_DD4 + Q_BB_D_DD_G_6_N_DD5 + Q_BB_D_DD_G_6_N_DD6 +
    Q_BB_D_DD_G_6_S_DD1 + Q_BB_D_DD_G_6_S_DD2 + Q_BB_D_DD_G_6_S_DD3 +
    Q_BB_D_DD_G_6_S_DD4 + Q_BB_D_DD_G_6_S_DD5 + Q_BB_D_DD_G_6_S_DD6 = 257.64;
    [_23] Q_BB_D_HH_G_7_E + Q_BB_D_HH_G_7_N + Q_BB_D_HH_G_7_S +
    Q_BB_D_DD_G_7_E_DD1 + Q_BB_D_DD_G_7_E_DD2 + Q_BB_D_DD_G_7_E_DD3 +
    Q_BB_D_DD_G_7_E_DD4 + Q_BB_D_DD_G_7_E_DD5 + Q_BB_D_DD_G_7_E_DD6 +
    Q_BB_D_DD_G_7_N_DD1 + Q_BB_D_DD_G_7_N_DD2 + Q_BB_D_DD_G_7_N_DD3 +
    Q_BB_D_DD_G_7_N_DD4 + Q_BB_D_DD_G_7_N_DD5 + Q_BB_D_DD_G_7_N_DD6 +
    Q_BB_D_DD_G_7_S_DD1 + Q_BB_D_DD_G_7_S_DD2 + Q_BB_D_DD_G_7_S_DD3 +
    Q_BB_D_DD_G_7_S_DD4 + Q_BB_D_DD_G_7_S_DD5 + Q_BB_D_DD_G_7_S_DD6 = 265.67;
    [_24] Q_BB_D_HH_G_8_E + Q_BB_D_HH_G_8_N + Q_BB_D_HH_G_8_S +
    Q_BB_D_DD_G_8_E_DD1 + Q_BB_D_DD_G_8_E_DD2 + Q_BB_D_DD_G_8_E_DD3 +
    Q_BB_D_DD_G_8_E_DD4 + Q_BB_D_DD_G_8_E_DD5 + Q_BB_D_DD_G_8_E_DD6 +
    Q_BB_D_DD_G_8_N_DD1 + Q_BB_D_DD_G_8_N_DD2 + Q_BB_D_DD_G_8_N_DD3 +
    Q_BB_D_DD_G_8_N_DD4 + Q_BB_D_DD_G_8_N_DD5 + Q_BB_D_DD_G_8_N_DD6 +
    Q_BB_D_DD_G_8_S_DD1 + Q_BB_D_DD_G_8_S_DD2 + Q_BB_D_DD_G_8_S_DD3 +
    Q_BB_D_DD_G_8_S_DD4 + Q_BB_D_DD_G_8_S_DD5 + Q_BB_D_DD_G_8_S_DD6 = 176.43;
    [_25] Q_BB_D_HH_G_9_E + Q_BB_D_HH_G_9_N + Q_BB_D_HH_G_9_S +
    Q_BB_D_DD_G_9_E_DD1 + Q_BB_D_DD_G_9_E_DD2 + Q_BB_D_DD_G_9_E_DD3 +
    Q_BB_D_DD_G_9_E_DD4 + Q_BB_D_DD_G_9_E_DD5 + Q_BB_D_DD_G_9_E_DD6 +
    Q_BB_D_DD_G_9_N_DD1 + Q_BB_D_DD_G_9_N_DD2 + Q_BB_D_DD_G_9_N_DD3 +
    Q_BB_D_DD_G_9_N_DD4 + Q_BB_D_DD_G_9_N_DD5 + Q_BB_D_DD_G_9_N_DD6 +
    Q_BB_D_DD_G_9_S_DD1 + Q_BB_D_DD_G_9_S_DD2 + Q_BB_D_DD_G_9_S_DD3 +
    Q_BB_D_DD_G_9_S_DD4 + Q_BB_D_DD_G_9_S_DD5 + Q_BB_D_DD_G_9_S_DD6 = 292.6;
    [_26] Q_BB_D_HH_G_10_E + Q_BB_D_HH_G_10_N + Q_BB_D_HH_G_10_S +
    Q_BB_D_DD_G_10_E_DD1 + Q_BB_D_DD_G_10_E_DD2 + Q_BB_D_DD_G_10_E_DD3 +
    Q_BB_D_DD_G_10_E_DD4 + Q_BB_D_DD_G_10_E_DD5 + Q_BB_D_DD_G_10_E_DD6 +
    Q_BB_D_DD_G_10_N_DD1 + Q_BB_D_DD_G_10_N_DD2 + Q_BB_D_DD_G_10_N_DD3 +
    Q_BB_D_DD_G_10_N_DD4 + Q_BB_D_DD_G_10_N_DD5 + Q_BB_D_DD_G_10_N_DD6 +
    Q_BB_D_DD_G_10_S_DD1 + Q_BB_D_DD_G_10_S_DD2 + Q_BB_D_DD_G_10_S_DD3 +
    Q_BB_D_DD_G_10_S_DD4 + Q_BB_D_DD_G_10_S_DD5 + Q_BB_D_DD_G_10_S_DD6 =
370.61;
    [_27] Q_BB_D_HH_G_11_E + Q_BB_D_HH_G_11_N + Q_BB_D_HH_G_11_S +
    Q_BB_D_DD_G_11_E_DD1 + Q_BB_D_DD_G_11_E_DD2 + Q_BB_D_DD_G_11_E_DD3 +
    Q_BB_D_DD_G_11_E_DD4 + Q_BB_D_DD_G_11_E_DD5 + Q_BB_D_DD_G_11_E_DD6 +
    Q_BB_D_DD_G_11_N_DD1 + Q_BB_D_DD_G_11_N_DD2 + Q_BB_D_DD_G_11_N_DD3 +
    Q_BB_D_DD_G_11_N_DD4 + Q_BB_D_DD_G_11_N_DD5 + Q_BB_D_DD_G_11_N_DD6 +
    Q_BB_D_DD_G_11_S_DD1 + Q_BB_D_DD_G_11_S_DD2 + Q_BB_D_DD_G_11_S_DD3 +
    Q_BB_D_DD_G_11_S_DD4 + Q_BB_D_DD_G_11_S_DD5 + Q_BB_D_DD_G_11_S_DD6 = 105;
    [_28] Q_BB_D_HH_G_12_E + Q_BB_D_HH_G_12_N + Q_BB_D_HH_G_12_S +
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Q_BB_D_DD_G_12_E_DD1 + Q_BB_D_DD_G_12_E_DD2 + Q_BB_D_DD_G_12_E_DD3 +
Q_BB_D_DD_G_12_E_DD4 + Q_BB_D_DD_G_12_E_DD5 + Q_BB_D_DD_G_12_E_DD6 +
Q_BB_D_DD_G_12_N_DD1 + Q_BB_D_DD_G_12_N_DD2 + Q_BB_D_DD_G_12_N_DD3 +
Q_BB_D_DD_G_12_N_DD4 + Q_BB_D_DD_G_12_N_DD5 + Q_BB_D_DD_G_12_N_DD6 +
Q_BB_D_DD_G_12_S_DD1 + Q_BB_D_DD_G_12_S_DD2 + Q_BB_D_DD_G_12_S_DD3 +
Q_BB_D_DD_G_12_S_DD4 + Q_BB_D_DD_G_12_S_DD5 + Q_BB_D_DD_G_12_S_DD6 =91.89;
[_29] Q_BB_D_HH_G_13_E + Q_BB_D_HH_G_13_N + Q_BB_D_HH_G_13_S +
Q_BB_D_DD_G_13_E_DD1 + Q_BB_D_DD_G_13_E_DD2 + Q_BB_D_DD_G_13_E_DD3 +
Q_BB_D_DD_G_13_E_DD4 + Q_BB_D_DD_G_13_E_DD5 + Q_BB_D_DD_G_13_E_DD6 +
Q_BB_D_DD_G_13_N_DD1 + Q_BB_D_DD_G_13_N_DD2 + Q_BB_D_DD_G_13_N_DD3 +
Q_BB_D_DD_G_13_N_DD4 + Q_BB_D_DD_G_13_N_DD5 + Q_BB_D_DD_G_13_N_DD6 +
Q_BB_D_DD_G_13_S_DD1 + Q_BB_D_DD_G_13_S_DD2 + Q_BB_D_DD_G_13_S_DD3 +
Q_BB_D_DD_G_13_S_DD4 + Q_BB_D_DD_G_13_S_DD5 + Q_BB_D_DD_G_13_S_DD6=172.75;
[_30] Q_BB_D_HH_G_14_E + Q_BB_D_HH_G_14_N + Q_BB_D_HH_G_14_S +
Q_BB_D_DD_G_14_E_DD1 + Q_BB_D_DD_G_14_E_DD2 + Q_BB_D_DD_G_14_E_DD3 +
Q_BB_D_DD_G_14_E_DD4 + Q_BB_D_DD_G_14_E_DD5 + Q_BB_D_DD_G_14_E_DD6 +
Q_BB_D_DD_G_14_N_DD1 + Q_BB_D_DD_G_14_N_DD2 + Q_BB_D_DD_G_14_N_DD3 +
Q_BB_D_DD_G_14_N_DD4 + Q_BB_D_DD_G_14_N_DD5 + Q_BB_D_DD_G_14_N_DD6 +
Q_BB_D_DD_G_14_S_DD1 + Q_BB_D_DD_G_14_S_DD2 + Q_BB_D_DD_G_14_S_DD3 +
Q_BB_D_DD_G_14_S_DD4 + Q_BB_D_DD_G_14_S_DD5 + Q_BB_D_DD_G_14_S_DD6=142.19;
[_31] Q_BB_D_HH_G_15_E + Q_BB_D_HH_G_15_N + Q_BB_D_HH_G_15_S +
Q_BB_D_DD_G_15_E_DD1 + Q_BB_D_DD_G_15_E_DD2 + Q_BB_D_DD_G_15_E_DD3 +
Q_BB_D_DD_G_15_E_DD4 + Q_BB_D_DD_G_15_E_DD5 + Q_BB_D_DD_G_15_E_DD6 +
Q_BB_D_DD_G_15_N_DD1 + Q_BB_D_DD_G_15_N_DD2 + Q_BB_D_DD_G_15_N_DD3 +
Q_BB_D_DD_G_15_N_DD4 + Q_BB_D_DD_G_15_N_DD5 + Q_BB_D_DD_G_15_N_DD6 +
Q_BB_D_DD_G_15_S_DD1 + Q_BB_D_DD_G_15_S_DD2 + Q_BB_D_DD_G_15_S_DD3 +
Q_BB_D_DD_G_15_S_DD4 + Q_BB_D_DD_G_15_S_DD5 + Q_BB_D_DD_G_15_S_DD6 =24.4 ;
[_32] Q_BB_D_DD_G_1_E_DD1 + Q_BB_D_DD_G_1_N_DD1 + Q_BB_D_DD_G_1_S_DD1
 <=1.9628;
[_33]Q_BB_D_DD_G_1_E_DD2 + Q_BB_D_DD_G_1_N_DD2 + Q_BB_D_DD_G_1_S_DD2
 <=27.4792;
[_34] Q_BB_D_DD_G_1_E_DD3 + Q_BB_D_DD_G_1_N_DD3 + Q_BB_D_DD_G_1_S_DD3 <=
25.5164 ;
[_35] Q_BB_D_DD_G_1_E_DD4 + Q_BB_D_DD_G_1_N_DD4 + Q_BB_D_DD_G_1_S_DD4 <=
62.8096 ;
[_36] Q_BB_D_DD_G_1_E_DD5 + Q_BB_D_DD_G_1_N_DD5 + Q_BB_D_DD_G_1_S_DD5 <=
89.50368 ;
[_37] Q_BB_D_DD_G_1_E_DD6 + Q_BB_D_DD_G_1_N_DD6 + Q_BB_D_DD_G_1_S_DD6 <=
0 ;
[_38] Q_BB_D_DD_G_2_E_DD1 + Q_BB_D_DD_G_2_N_DD1 + Q_BB_D_DD_G_2_S_DD1 <=
0 ;
[_39] Q_BB_D_DD_G_2_E_DD2 + Q_BB_D_DD_G_2_N_DD2 + Q_BB_D_DD_G_2_S_DD2 <=
26.9682 ;
[_40] Q_BB_D_DD_G_2_E_DD3 + Q_BB_D_DD_G_2_N_DD3 + Q_BB_D_DD_G_2_S_DD3 <=
13.4841 ;
[_41] Q_BB_D_DD_G_2_E_DD4 + Q_BB_D_DD_G_2_N_DD4 + Q_BB_D_DD_G_2_S_DD4 <=
63.5679 ;
[_42] Q_BB_D_DD_G_2_E_DD5 + Q_BB_D_DD_G_2_N_DD5 + Q_BB_D_DD_G_2_S_DD5 <=
92.46239999999999 ;
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[_43] Q_BB_D_DD_G_2_E_DD6 + Q_BB_D_DD_G_2_N_DD6 + Q_BB_D_DD_G_2_S_DD6 <=0;
[_44] Q_BB_D_DD_G_3_E_DD1 + Q_BB_D_DD_G_3_N_DD1 + Q_BB_D_DD_G_3_S_DD1 <=
7.897200000000001 ;
[_45] Q_BB_D_DD_G_3_E_DD2 + Q_BB_D_DD_G_3_N_DD2 + Q_BB_D_DD_G_3_S_DD2 <=
37.51170000000001 ;
[_46] Q_BB_D_DD_G_3_E_DD3 + Q_BB_D_DD_G_3_N_DD3 + Q_BB_D_DD_G_3_S_DD3 <=
19.743 ;
[_47] Q_BB_D_DD_G_3_E_DD4 + Q_BB_D_DD_G_3_N_DD4 + Q_BB_D_DD_G_3_S_DD4 <=
61.2033 ;
[_48] Q_BB_D_DD_G_3_E_DD5 + Q_BB_D_DD_G_3_N_DD5 + Q_BB_D_DD_G_3_S_DD5 <=
88.84350000000001 ;
[_49] Q_BB_D_DD_G_3_E_DD6 + Q_BB_D_DD_G_3_N_DD6 + Q_BB_D_DD_G_3_S_DD6 <=0;
[_50] Q_BB_D_DD_G_4_E_DD1 + Q_BB_D_DD_G_4_N_DD1 + Q_BB_D_DD_G_4_S_DD1 <=0;
[_51] Q_BB_D_DD_G_4_E_DD2 + Q_BB_D_DD_G_4_N_DD2 + Q_BB_D_DD_G_4_S_DD2 <=
20.622 ;
[_52] Q_BB_D_DD_G_4_E_DD3 + Q_BB_D_DD_G_4_N_DD3 + Q_BB_D_DD_G_4_S_DD3 <=
20.9657 ;
[_53] Q_BB_D_DD_G_4_E_DD4 + Q_BB_D_DD_G_4_N_DD4 + Q_BB_D_DD_G_4_S_DD4 <=
56.7105 ;
[_54] Q_BB_D_DD_G_4_E_DD5 + Q_BB_D_DD_G_4_N_DD5 + Q_BB_D_DD_G_4_S_DD5 <=
80.76949999999999 ;
[_55] Q_BB_D_DD_G_4_E_DD6 + Q_BB_D_DD_G_4_N_DD6 + Q_BB_D_DD_G_4_S_DD6 <=0;
[_56] Q_BB_D_DD_G_5_E_DD1 + Q_BB_D_DD_G_5_N_DD1 + Q_BB_D_DD_G_5_S_DD1 <=0;
[_57] Q_BB_D_DD_G_5_E_DD2 + Q_BB_D_DD_G_5_N_DD2 + Q_BB_D_DD_G_5_S_DD2 <=
2.0733 ;
[_58] Q_BB_D_DD_G_5_E_DD3 + Q_BB_D_DD_G_5_N_DD3 + Q_BB_D_DD_G_5_S_DD3 <=
28.19688 ;
[_59] Q_BB_D_DD_G_5_E_DD4 + Q_BB_D_DD_G_5_N_DD4 + Q_BB_D_DD_G_5_S_DD4 <=
72.15084 ;
[_60] Q_BB_D_DD_G_5_E_DD5 + Q_BB_D_DD_G_5_N_DD5 + Q_BB_D_DD_G_5_S_DD5 <=
103.04301 ;
[_61] Q_BB_D_DD_G_5_E_DD6 + Q_BB_D_DD_G_5_N_DD6 + Q_BB_D_DD_G_5_S_DD6 <=0;
[_62] Q_BB_D_DD_G_6_E_DD1 + Q_BB_D_DD_G_6_N_DD1 + Q_BB_D_DD_G_6_S_DD1 <=0;
[_63] Q_BB_D_DD_G_6_E_DD2 + Q_BB_D_DD_G_6_N_DD2 + Q_BB_D_DD_G_6_S_DD2 <=
2.5764 ;
[_64] Q_BB_D_DD_G_6_E_DD3 + Q_BB_D_DD_G_6_N_DD3 + Q_BB_D_DD_G_6_S_DD3 <=
25.764 ;
[_65] Q_BB_D_DD_G_6_E_DD4 + Q_BB_D_DD_G_6_N_DD4 + Q_BB_D_DD_G_6_S_DD4 <=
94.81151999999999 ;
[_66] Q_BB_D_DD_G_6_E_DD5 + Q_BB_D_DD_G_6_N_DD5 + Q_BB_D_DD_G_6_S_DD5 <=
135.77628 ;
[_67] Q_BB_D_DD_G_6_E_DD6 + Q_BB_D_DD_G_6_N_DD6 + Q_BB_D_DD_G_6_S_DD6 <=
0 ;
[_68] Q_BB_D_DD_G_7_E_DD1 + Q_BB_D_DD_G_7_N_DD1 + Q_BB_D_DD_G_7_S_DD1 <=
0 ;
[_69] Q_BB_D_DD_G_7_E_DD2 + Q_BB_D_DD_G_7_N_DD2 + Q_BB_D_DD_G_7_S_DD2 <=
31.8804 ;
[_70] Q_BB_D_DD_G_7_E_DD3 + Q_BB_D_DD_G_7_N_DD3 + Q_BB_D_DD_G_7_S_DD3 <=
18.5969 ;
```

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[_71] Q_BB_D_DD_G_7_E_DD4 + Q_BB_D_DD_G_7_N_DD4 + Q_BB_D_DD_G_7_S_DD4 <=
92.9845 ;
[_72] Q_BB_D_DD_G_7_E_DD5 + Q_BB_D_DD_G_7_N_DD5 + Q_BB_D_DD_G_7_S_DD5 <=
132.835 ;
[_73] Q_BB_D_DD_G_7_E_DD6 + Q_BB_D_DD_G_7_N_DD6 + Q_BB_D_DD_G_7_S_DD6 <=
0 ;
[_74] Q_BB_D_DD_G_8_E_DD1 + Q_BB_D_DD_G_8_N_DD1 + Q_BB_D_DD_G_8_S_DD1 <=
0 ;
[_75] Q_BB_D_DD_G_8_E_DD2 + Q_BB_D_DD_G_8_N_DD2 + Q_BB_D_DD_G_8_S_DD2 <=
24.7002 ;
[_76] Q_BB_D_DD_G_8_E_DD3 + Q_BB_D_DD_G_8_N_DD3 + Q_BB_D_DD_G_8_S_DD3 <=
17.643 ;
[_77] Q_BB_D_DD_G_8_E_DD4 + Q_BB_D_DD_G_8_N_DD4 + Q_BB_D_DD_G_8_S_DD4 <=
60.69192 ;
[_78] Q_BB_D_DD_G_8_E_DD5 + Q_BB_D_DD_G_8_N_DD5 + Q_BB_D_DD_G_8_S_DD5 <=
86.4507 ;
[_79] Q_BB_D_DD_G_8_E_DD6 + Q_BB_D_DD_G_8_N_DD6 + Q_BB_D_DD_G_8_S_DD6 <=
0 ;
[_80] Q_BB_D_DD_G_9_E_DD1 + Q_BB_D_DD_G_9_N_DD1 + Q_BB_D_DD_G_9_S_DD1 <=
0 ;
[_81] Q_BB_D_DD_G_9_E_DD2 + Q_BB_D_DD_G_9_N_DD2 + Q_BB_D_DD_G_9_S_DD2 <=
38.038 ;
[_82] Q_BB_D_DD_G_9_E_DD3 + Q_BB_D_DD_G_9_N_DD3 + Q_BB_D_DD_G_9_S_DD3 <=
26.334 ;
[_83] Q_BB_D_DD_G_9_E_DD4 + Q_BB_D_DD_G_9_N_DD4 + Q_BB_D_DD_G_9_S_DD4 <=
98.89880000000001 ;
[_84] Q_BB_D_DD_G_9_E_DD5 + Q_BB_D_DD_G_9_N_DD5 + Q_BB_D_DD_G_9_S_DD5 <=
141.0332 ;
[_85] Q_BB_D_DD_G_9_E_DD6 + Q_BB_D_DD_G_9_N_DD6 + Q_BB_D_DD_G_9_S_DD6 <=
0 ;
[_86] Q_BB_D_DD_G_10_E_DD1 + Q_BB_D_DD_G_10_N_DD1 + Q_BB_D_DD_G_10_S_DD1
<= 0 ;
[_87] Q_BB_D_DD_G_10_E_DD2 + Q_BB_D_DD_G_10_N_DD2 + Q_BB_D_DD_G_10_S_DD2
<= 48.17930000000001 ;
[_88] Q_BB_D_DD_G_10_E_DD3 + Q_BB_D_DD_G_10_N_DD3 + Q_BB_D_DD_G_10_S_DD3
<= 0 ;
[_89] Q_BB_D_DD_G_10_E_DD4 + Q_BB_D_DD_G_10_N_DD4 + Q_BB_D_DD_G_10_S_DD4
<= 132.30777 ;
[_90] Q_BB_D_DD_G_10_E_DD5 + Q_BB_D_DD_G_10_N_DD5 + Q_BB_D_DD_G_10_S_DD5
<= 189.0111 ;
[_91] Q_BB_D_DD_G_10_E_DD6 + Q_BB_D_DD_G_10_N_DD6 + Q_BB_D_DD_G_10_S_DD6
<= 0 ;
[_92] Q_BB_D_DD_G_11_E_DD1 + Q_BB_D_DD_G_11_N_DD1 + Q_BB_D_DD_G_11_S_DD1
<= 24.15 ;
[_93] Q_BB_D_DD_G_11_E_DD2 + Q_BB_D_DD_G_11_N_DD2 + Q_BB_D_DD_G_11_S_DD2
<= 0 ;
[_94] Q_BB_D_DD_G_11_E_DD3 + Q_BB_D_DD_G_11_N_DD3 + Q_BB_D_DD_G_11_S_DD3
<= 9.449999999999999 ;
[_95] Q_BB_D_DD_G_11_E_DD4 + Q_BB_D_DD_G_11_N_DD4 + Q_BB_D_DD_G_11_S_DD4
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<= 23.1 ;
[_96] Q_BB_D_DD_G_11_E_DD5 + Q_BB_D_DD_G_11_N_DD5 + Q_BB_D_DD_G_11_S_DD5
<= 5.25 ;
[_97] Q_BB_D_DD_G_11_E_DD6 + Q_BB_D_DD_G_11_N_DD6 + Q_BB_D_DD_G_11_S_DD6
<= 18.9 ;
[_98] Q_BB_D_DD_G_12_E_DD1 + Q_BB_D_DD_G_12_N_DD1 + Q_BB_D_DD_G_12_S_DD1
<= 20.2158 ;
[_99] Q_BB_D_DD_G_12_E_DD2 + Q_BB_D_DD_G_12_N_DD2 + Q_BB_D_DD_G_12_S_DD2
<= 0 ;
[_100] Q_BB_D_DD_G_12_E_DD3 + Q_BB_D_DD_G_12_N_DD3 +
Q_BB_D_DD_G_12_S_DD3 <= 9.189 ;
[_101] Q_BB_D_DD_G_12_E_DD4 + Q_BB_D_DD_G_12_N_DD4 +
Q_BB_D_DD_G_12_S_DD4 <= 19.2969 ;
[_102] Q_BB_D_DD_G_12_E_DD5 + Q_BB_D_DD_G_12_N_DD5 +
Q_BB_D_DD_G_12_S_DD5 <= 44.1072 ;
[_103] Q_BB_D_DD_G_12_E_DD6 + Q_BB_D_DD_G_12_N_DD6 +
Q_BB_D_DD_G_12_S_DD6 <= 13.7835 ;
[_104] Q_BB_D_DD_G_13_E_DD1 + Q_BB_D_DD_G_13_N_DD1 +
Q_BB_D_DD_G_13_S_DD1 <= 32.1315 ;
[_105] Q_BB_D_DD_G_13_E_DD2 + Q_BB_D_DD_G_13_N_DD2 +
Q_BB_D_DD_G_13_S_DD2 <= 0 ;
[_106] Q_BB_D_DD_G_13_E_DD3 + Q_BB_D_DD_G_13_N_DD3 +
Q_BB_D_DD_G_13_S_DD3 <= 20.73 ;
[_107] Q_BB_D_DD_G_13_E_DD4 + Q_BB_D_DD_G_13_N_DD4 +
Q_BB_D_DD_G_13_S_DD4 <= 31.095 ;
[_108] Q_BB_D_DD_G_13_E_DD5 + Q_BB_D_DD_G_13_N_DD5 +
Q_BB_D_DD_G_13_S_DD5 <= 39.7325 ;
[_109] Q_BB_D_DD_G_13_E_DD6 + Q_BB_D_DD_G_13_N_DD6 +
Q_BB_D_DD_G_13_S_DD6 <= 22.4575 ;
[_110] Q_BB_D_DD_G_14_E_DD1 + Q_BB_D_DD_G_14_N_DD1 +
Q_BB_D_DD_G_14_S_DD1 <= 19.90758 ;
[_111] Q_BB_D_DD_G_14_E_DD2 + Q_BB_D_DD_G_14_N_DD2 +
Q_BB_D_DD_G_14_S_DD2 <= 0 ;
[_112] Q_BB_D_DD_G_14_E_DD3 + Q_BB_D_DD_G_14_N_DD3 +
Q_BB_D_DD_G_14_S_DD3 <= 17.06364 ;
[_113] Q_BB_D_DD_G_14_E_DD4 + Q_BB_D_DD_G_14_N_DD4 +
Q_BB_D_DD_G_14_S_DD4 <= 27.01743 ;
[_114] Q_BB_D_DD_G_14_E_DD5 + Q_BB_D_DD_G_14_N_DD5 +
Q_BB_D_DD_G_14_S_DD5 <= 49.76895 ;
[_115] Q_BB_D_DD_G_14_E_DD6 + Q_BB_D_DD_G_14_N_DD6 +
Q_BB_D_DD_G_14_S_DD6 <= 21.32955 ;
[_116] Q_BB_D_DD_G_15_E_DD1 + Q_BB_D_DD_G_15_N_DD1 +
Q_BB_D_DD_G_15_S_DD1 <= 0 ;
[_117] Q_BB_D_DD_G_15_E_DD2 + Q_BB_D_DD_G_15_N_DD2 +
Q_BB_D_DD_G_15_S_DD2 <= 0 ;
[_118] Q_BB_D_DD_G_15_E_DD3 + Q_BB_D_DD_G_15_N_DD3 +
Q_BB_D_DD_G_15_S_DD3 <= 0.244 ;
[_119] Q_BB_D_DD_G_15_E_DD4 + Q_BB_D_DD_G_15_N_DD4 +
Q_BB_D_DD_G_15_S_DD4 <= 0 ;
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[_120] Q_BB_D_DD_G_15_E_DD5 + Q_BB_D_DD_G_15_N_DD5 +
Q_BB_D_DD_G_15_S_DD5 <= 0 ;
[_121] Q_BB_D_DD_G_15_E_DD6 + Q_BB_D_DD_G_15_N_DD6 +
Q_BB_D_DD_G_15_S_DD6 <= 0 ;
[_122] Q_BB_D_DD_G_1_E_DD1 + Q_BB_D_DD_G_1_N_DD1 + Q_BB_D_DD_G_1_S_DD1
>= 0 ;
[_123] Q_BB_D_DD_G_1_E_DD2 + Q_BB_D_DD_G_1_N_DD2 + Q_BB_D_DD_G_1_S_DD2
>= 7.8512 ;
[_124] Q_BB_D_DD_G_1_E_DD3 + Q_BB_D_DD_G_1_N_DD3 + Q_BB_D_DD_G_1_S_DD3
>= 5.8884 ;
[_125] Q_BB_D_DD_G_1_E_DD4 + Q_BB_D_DD_G_1_N_DD4 + Q_BB_D_DD_G_1_S_DD4
>= 43.1816 ;
[_126] Q_BB_D_DD_G_1_E_DD5 + Q_BB_D_DD_G_1_N_DD5 + Q_BB_D_DD_G_1_S_DD5
>= 69.87568 ;
[_127] Q_BB_D_DD_G_1_E_DD6 + Q_BB_D_DD_G_1_N_DD6 + Q_BB_D_DD_G_1_S_DD6
>= 0 ;
[_128] Q_BB_D_DD_G_2_E_DD1 + Q_BB_D_DD_G_2_N_DD1 + Q_BB_D_DD_G_2_S_DD1
>= 0 ;
[_129] Q_BB_D_DD_G_2_E_DD2 + Q_BB_D_DD_G_2_N_DD2 + Q_BB_D_DD_G_2_S_DD2
>= 7.7052 ;
[_130] Q_BB_D_DD_G_2_E_DD3 + Q_BB_D_DD_G_2_N_DD3 + Q_BB_D_DD_G_2_S_DD3
>= 0 ;
[_131] Q_BB_D_DD_G_2_E_DD4 + Q_BB_D_DD_G_2_N_DD4 + Q_BB_D_DD_G_2_S_DD4
>= 44.3049 ;
[_132] Q_BB_D_DD_G_2_E_DD5 + Q_BB_D_DD_G_2_N_DD5 + Q_BB_D_DD_G_2_S_DD5
>= 73.1994 ;
[_133] Q_BB_D_DD_G_2_E_DD6 + Q_BB_D_DD_G_2_N_DD6 + Q_BB_D_DD_G_2_S_DD6
>= 0 ;
[_134] Q_BB_D_DD_G_3_E_DD1 + Q_BB_D_DD_G_3_N_DD1 + Q_BB_D_DD_G_3_S_DD1
>= 0 ;
[_135] Q_BB_D_DD_G_3_E_DD2 + Q_BB_D_DD_G_3_N_DD2 + Q_BB_D_DD_G_3_S_DD2
>= 17.7687 ;
[_136] Q_BB_D_DD_G_3_E_DD3 + Q_BB_D_DD_G_3_N_DD3 + Q_BB_D_DD_G_3_S_DD3
>= 0 ;
[_137] Q_BB_D_DD_G_3_E_DD4 + Q_BB_D_DD_G_3_N_DD4 + Q_BB_D_DD_G_3_S_DD4
>= 41.4603 ;
[_138] Q_BB_D_DD_G_3_E_DD5 + Q_BB_D_DD_G_3_N_DD5 + Q_BB_D_DD_G_3_S_DD5
>= 69.1005 ;
[_139] Q_BB_D_DD_G_3_E_DD6 + Q_BB_D_DD_G_3_N_DD6 + Q_BB_D_DD_G_3_S_DD6
>= 0 ;
[_140] Q_BB_D_DD_G_4_E_DD1 + Q_BB_D_DD_G_4_N_DD1 + Q_BB_D_DD_G_4_S_DD1
>= 0 ;
[_141] Q_BB_D_DD_G_4_E_DD2 + Q_BB_D_DD_G_4_N_DD2 + Q_BB_D_DD_G_4_S_DD2
>= 3.437 ;
[_142] Q_BB_D_DD_G_4_E_DD3 + Q_BB_D_DD_G_4_N_DD3 + Q_BB_D_DD_G_4_S_DD3
>= 3.7807 ;
[_143] Q_BB_D_DD_G_4_E_DD4 + Q_BB_D_DD_G_4_N_DD4 + Q_BB_D_DD_G_4_S_DD4
>= 39.5255 ;
[_144] Q_BB_D_DD_G_4_E_DD5 + Q_BB_D_DD_G_4_N_DD5 + Q_BB_D_DD_G_4_S_DD5
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>= 63.5845 ;
[_145] Q_BB_D_DD_G_4_E_DD6 + Q_BB_D_DD_G_4_N_DD6 + Q_BB_D_DD_G_4_S_DD6
>= 0 ;
[_146] Q_BB_D_DD_G_5_E_DD1 + Q_BB_D_DD_G_5_N_DD1 + Q_BB_D_DD_G_5_S_DD1
>= 0 ;
[_147] Q_BB_D_DD_G_5_E_DD2 + Q_BB_D_DD_G_5_N_DD2 + Q_BB_D_DD_G_5_S_DD2
>= 0 ;
[_148] Q_BB_D_DD_G_5_E_DD3 + Q_BB_D_DD_G_5_N_DD3 + Q_BB_D_DD_G_5_S_DD3
>= 7.46388 ;
[_149] Q_BB_D_DD_G_5_E_DD4 + Q_BB_D_DD_G_5_N_DD4 + Q_BB_D_DD_G_5_S_DD4
>= 51.41784000000001 ;
[_150] Q_BB_D_DD_G_5_E_DD5 + Q_BB_D_DD_G_5_N_DD5 + Q_BB_D_DD_G_5_S_DD5
>= 82.31001000000001 ;
[_151] Q_BB_D_DD_G_5_E_DD6 + Q_BB_D_DD_G_5_N_DD6 + Q_BB_D_DD_G_5_S_DD6
>= 0 ;
[_152] Q_BB_D_DD_G_6_E_DD1 + Q_BB_D_DD_G_6_N_DD1 + Q_BB_D_DD_G_6_S_DD1
>= 0 ;
[_153] Q_BB_D_DD_G_6_E_DD2 + Q_BB_D_DD_G_6_N_DD2 + Q_BB_D_DD_G_6_S_DD2
>= 0 ;
[_154] Q_BB_D_DD_G_6_E_DD3 + Q_BB_D_DD_G_6_N_DD3 + Q_BB_D_DD_G_6_S_DD3
>= 0 ;
[_155] Q_BB_D_DD_G_6_E_DD4 + Q_BB_D_DD_G_6_N_DD4 + Q_BB_D_DD_G_6_S_DD4
>= 69.04752000000001 ;
[_156] Q_BB_D_DD_G_6_E_DD5 + Q_BB_D_DD_G_6_N_DD5 + Q_BB_D_DD_G_6_S_DD5
>= 110.01228 ;
[_157] Q_BB_D_DD_G_6_E_DD6 + Q_BB_D_DD_G_6_N_DD6 + Q_BB_D_DD_G_6_S_DD6
>= 0 ;
[_158] Q_BB_D_DD_G_7_E_DD1 + Q_BB_D_DD_G_7_N_DD1 + Q_BB_D_DD_G_7_S_DD1
>= 0 ;
[_159] Q_BB_D_DD_G_7_E_DD2 + Q_BB_D_DD_G_7_N_DD2 + Q_BB_D_DD_G_7_S_DD2
>= 5.313400000000001 ;
[_160] Q_BB_D_DD_G_7_E_DD3 + Q_BB_D_DD_G_7_N_DD3 + Q_BB_D_DD_G_7_S_DD3
>= 0 ;
[_161] Q_BB_D_DD_G_7_E_DD4 + Q_BB_D_DD_G_7_N_DD4 + Q_BB_D_DD_G_7_S_DD4
>= 66.4175 ;
[_162] Q_BB_D_DD_G_7_E_DD5 + Q_BB_D_DD_G_7_N_DD5 + Q_BB_D_DD_G_7_S_DD5
>= 106.268 ;
[_163] Q_BB_D_DD_G_7_E_DD6 + Q_BB_D_DD_G_7_N_DD6 + Q_BB_D_DD_G_7_S_DD6
>= 0 ;
[_164] Q_BB_D_DD_G_8_E_DD1 + Q_BB_D_DD_G_8_N_DD1 + Q_BB_D_DD_G_8_S_DD1
>= 0 ;
[_165] Q_BB_D_DD_G_8_E_DD2 + Q_BB_D_DD_G_8_N_DD2 + Q_BB_D_DD_G_8_S_DD2
>= 7.057200000000001 ;
[_166] Q_BB_D_DD_G_8_E_DD3 + Q_BB_D_DD_G_8_N_DD3 + Q_BB_D_DD_G_8_S_DD3
>= 0 ;
[_167] Q_BB_D_DD_G_8_E_DD4 + Q_BB_D_DD_G_8_N_DD4 + Q_BB_D_DD_G_8_S_DD4
>= 43.04892 ;
[_168] Q_BB_D_DD_G_8_E_DD5 + Q_BB_D_DD_G_8_N_DD5 + Q_BB_D_DD_G_8_S_DD5
>= 68.80770000000001 ;
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[_169] Q_BB_D_DD_G_8_E_DD6 + Q_BB_D_DD_G_8_N_DD6 + Q_BB_D_DD_G_8_S_DD6
>= 0 ;
[_170] Q_BB_D_DD_G_9_E_DD1 + Q_BB_D_DD_G_9_N_DD1 + Q_BB_D_DD_G_9_S_DD1
>= 0 ;
[_171] Q_BB_D_DD_G_9_E_DD2 + Q_BB_D_DD_G_9_N_DD2 + Q_BB_D_DD_G_9_S_DD2
>= 8.778000000000001 ;
[_172] Q_BB_D_DD_G_9_E_DD3 + Q_BB_D_DD_G_9_N_DD3 + Q_BB_D_DD_G_9_S_DD3
>= 0 ;
[_173] Q_BB_D_DD_G_9_E_DD4 + Q_BB_D_DD_G_9_N_DD4 + Q_BB_D_DD_G_9_S_DD4
>= 69.6388 ;
[_174] Q_BB_D_DD_G_9_E_DD5 + Q_BB_D_DD_G_9_N_DD5 + Q_BB_D_DD_G_9_S_DD5
>= 111.7732 ;
[_175] Q_BB_D_DD_G_9_E_DD6 + Q_BB_D_DD_G_9_N_DD6 + Q_BB_D_DD_G_9_S_DD6
>= 0 ;
[_176] Q_BB_D_DD_G_10_E_DD1 + Q_BB_D_DD_G_10_N_DD1 +
Q_BB_D_DD_G_10_S_DD1 >= 0 ;
[_177] Q_BB_D_DD_G_10_E_DD2 + Q_BB_D_DD_G_10_N_DD2 +
Q_BB_D_DD_G_10_S_DD2 >= 11.1183 ;
[_178] Q_BB_D_DD_G_10_E_DD3 + Q_BB_D_DD_G_10_N_DD3 +
Q_BB_D_DD_G_10_S_DD3 >= 0 ;
[_179] Q_BB_D_DD_G_10_E_DD4 + Q_BB_D_DD_G_10_N_DD4 +
Q_BB_D_DD_G_10_S_DD4 >= 95.24677000000001 ;
[_180] Q_BB_D_DD_G_10_E_DD5 + Q_BB_D_DD_G_10_N_DD5 +
Q_BB_D_DD_G_10_S_DD5 >= 151.9501 ;
[_181] Q_BB_D_DD_G_10_E_DD6 + Q_BB_D_DD_G_10_N_DD6 +
Q_BB_D_DD_G_10_S_DD6 >= 0 ;
[_182] Q_BB_D_DD_G_11_E_DD1 + Q_BB_D_DD_G_11_N_DD1 +
Q_BB_D_DD_G_11_S_DD1 >= 13.65 ;
[_183] Q_BB_D_DD_G_11_E_DD2 + Q_BB_D_DD_G_11_N_DD2 +
Q_BB_D_DD_G_11_S_DD2 >= 0 ;
[_184] Q_BB_D_DD_G_11_E_DD3 + Q_BB_D_DD_G_11_N_DD3 +
Q_BB_D_DD_G_11_S_DD3 >= 0 ;
[_185] Q_BB_D_DD_G_11_E_DD4 + Q_BB_D_DD_G_11_N_DD4 +
Q_BB_D_DD_G_11_S_DD4 >= 12.6 ;
[_186] Q_BB_D_DD_G_11_E_DD5 + Q_BB_D_DD_G_11_N_DD5 +
Q_BB_D_DD_G_11_S_DD5 >= 0 ;
[_187] Q_BB_D_DD_G_11_E_DD6 + Q_BB_D_DD_G_11_N_DD6 +
Q_BB_D_DD_G_11_S_DD6 >= 8.4 ;
[_188] Q_BB_D_DD_G_12_E_DD1 + Q_BB_D_DD_G_12_N_DD1 +
Q_BB_D_DD_G_12_S_DD1 >= 11.0268 ;
[_189] Q_BB_D_DD_G_12_E_DD2 + Q_BB_D_DD_G_12_N_DD2 +
Q_BB_D_DD_G_12_S_DD2 >= 0 ;
[_190] Q_BB_D_DD_G_12_E_DD3 + Q_BB_D_DD_G_12_N_DD3 +
Q_BB_D_DD_G_12_S_DD3 >= 0 ;
[_191] Q_BB_D_DD_G_12_E_DD4 + Q_BB_D_DD_G_12_N_DD4 +
Q_BB_D_DD_G_12_S_DD4 >= 10.1079 ;
[_192] Q_BB_D_DD_G_12_E_DD5 + Q_BB_D_DD_G_12_N_DD5 +
Q_BB_D_DD_G_12_S_DD5 >= 34.9182 ;
[_193] Q_BB_D_DD_G_12_E_DD6 + Q_BB_D_DD_G_12_N_DD6 +
```

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Q_BB_D_DD_G_12_S_DD6 >= 4.5945 ;
[_194] Q_BB_D_DD_G_13_E_DD1 + Q_BB_D_DD_G_13_N_DD1 +
Q_BB_D_DD_G_13_S_DD1 >= 14.8565 ;
[_195] Q_BB_D_DD_G_13_E_DD2 + Q_BB_D_DD_G_13_N_DD2 +
Q_BB_D_DD_G_13_S_DD2 >= 0 ;
[_196] Q_BB_D_DD_G_13_E_DD3 + Q_BB_D_DD_G_13_N_DD3 +
Q_BB_D_DD_G_13_S_DD3 >= 3.455 ;
[_197] Q_BB_D_DD_G_13_E_DD4 + Q_BB_D_DD_G_13_N_DD4 +
Q_BB_D_DD_G_13_S_DD4 >= 13.82 ;
[_198] Q_BB_D_DD_G_13_E_DD5 + Q_BB_D_DD_G_13_N_DD5 +
Q_BB_D_DD_G_13_S_DD5 >= 22.4575 ;
[_199] Q_BB_D_DD_G_13_E_DD6 + Q_BB_D_DD_G_13_N_DD6 +
Q_BB_D_DD_G_13_S_DD6 >= 5.1825 ;
[_200] Q_BB_D_DD_G_14_E_DD1 + Q_BB_D_DD_G_14_N_DD1 +
Q_BB_D_DD_G_14_S_DD1 >= 5.68788 ;
[_201] Q_BB_D_DD_G_14_E_DD2 + Q_BB_D_DD_G_14_N_DD2 +
Q_BB_D_DD_G_14_S_DD2 >= 0 ;
[_202] Q_BB_D_DD_G_14_E_DD3 + Q_BB_D_DD_G_14_N_DD3 +
Q_BB_D_DD_G_14_S_DD3 >= 2.84394 ;
[_203] Q_BB_D_DD_G_14_E_DD4 + Q_BB_D_DD_G_14_N_DD4 +
Q_BB_D_DD_G_14_S_DD4 >= 12.79773 ;
[_204] Q_BB_D_DD_G_14_E_DD5 + Q_BB_D_DD_G_14_N_DD5 +
Q_BB_D_DD_G_14_S_DD5 >= 35.54925 ;
[_205] Q_BB_D_DD_G_14_E_DD6 + Q_BB_D_DD_G_14_N_DD6 +
Q_BB_D_DD_G_14_S_DD6 >= 7.109850000000001 ;
[_206] Q_BB_D_DD_G_15_E_DD1 + Q_BB_D_DD_G_15_N_DD1 +
Q_BB_D_DD_G_15_S_DD1 >= 0 ;
[_207] Q_BB_D_DD_G_15_E_DD2 + Q_BB_D_DD_G_15_N_DD2 +
Q_BB_D_DD_G_15_S_DD2 >= 0 ;
[_208] Q_BB_D_DD_G_15_E_DD3 + Q_BB_D_DD_G_15_N_DD3 +
Q_BB_D_DD_G_15_S_DD3 >= 0 ;
[_209] Q_BB_D_DD_G_15_E_DD4 + Q_BB_D_DD_G_15_N_DD4 +
Q_BB_D_DD_G_15_S_DD4 >= 0 ;
[_210] Q_BB_D_DD_G_15_E_DD5 + Q_BB_D_DD_G_15_N_DD5 +
Q_BB_D_DD_G_15_S_DD5 >= 0 ;
[_211] Q_BB_D_DD_G_15_E_DD6 + Q_BB_D_DD_G_15_N_DD6 +
Q_BB_D_DD_G_15_S_DD6 >= 0 ;
[_212] Q_BB_D_HH_G_1_E + Q_BB_D_HH_G_1_N + Q_BB_D_HH_G_1_S <= 39.256 ;
[_213] Q_BB_D_HH_G_2_E + Q_BB_D_HH_G_2_N + Q_BB_D_HH_G_2_S <= 38.526 ;
[_214] Q_BB_D_HH_G_3_E + Q_BB_D_HH_G_3_N + Q_BB_D_HH_G_3_S <= 35.5374 ;
[_215] Q_BB_D_HH_G_4_E + Q_BB_D_HH_G_4_N + Q_BB_D_HH_G_4_S <= 34.37 ;
[_216] Q_BB_D_HH_G_5_E + Q_BB_D_HH_G_5_N + Q_BB_D_HH_G_5_S <=
41.46600000000001 ;
[_217] Q_BB_D_HH_G_6_E + Q_BB_D_HH_G_6_N + Q_BB_D_HH_G_6_S <=
46.37519999999999 ;
[_218] Q_BB_D_HH_G_7_E + Q_BB_D_HH_G_7_N + Q_BB_D_HH_G_7_S <=
50.47730000000001 ;
[_219] Q_BB_D_HH_G_8_E + Q_BB_D_HH_G_8_N + Q_BB_D_HH_G_8_S <= 29.9931 ;
[_220] Q_BB_D_HH_G_9_E + Q_BB_D_HH_G_9_N + Q_BB_D_HH_G_9_S <=
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58.52000000000001 ;
[_221] Q_BB_D_HH_G_10_E + Q_BB_D_HH_G_10_N + Q_BB_D_HH_G_10_S <= 74.122
;
[_222] Q_BB_D_HH_G_11_E + Q_BB_D_HH_G_11_N + Q_BB_D_HH_G_11_S <= 51.45 ;
[_223] Q_BB_D_HH_G_12_E + Q_BB_D_HH_G_12_N + Q_BB_D_HH_G_12_S <= 11.0268
;
[_224] Q_BB_D_HH_G_13_E + Q_BB_D_HH_G_13_N + Q_BB_D_HH_G_13_S <=
58.73500000000001 ;
[_225] Q_BB_D_HH_G_14_E + Q_BB_D_HH_G_14_N + Q_BB_D_HH_G_14_S <=
48.34698 ;
[_226] Q_BB_D_HH_G_15_E + Q_BB_D_HH_G_15_N + Q_BB_D_HH_G_15_S <= 24.4 ;
[_227] Q_BB_D_HH_G_1_E + Q_BB_D_HH_G_1_N + Q_BB_D_HH_G_1_S >= 19.628 ;
[_228] Q_BB_D_HH_G_2_E + Q_BB_D_HH_G_2_N + Q_BB_D_HH_G_2_S >= 19.263 ;
[_229] Q_BB_D_HH_G_3_E + Q_BB_D_HH_G_3_N + Q_BB_D_HH_G_3_S >= 15.7944 ;
[_230] Q_BB_D_HH_G_4_E + Q_BB_D_HH_G_4_N + Q_BB_D_HH_G_4_S >= 17.185 ;
[_231] Q_BB_D_HH_G_5_E + Q_BB_D_HH_G_5_N + Q_BB_D_HH_G_5_S >= 20.733 ;
[_232] Q_BB_D_HH_G_6_E + Q_BB_D_HH_G_6_N + Q_BB_D_HH_G_6_S >= 20.6112 ;
[_233] Q_BB_D_HH_G_7_E + Q_BB_D_HH_G_7_N + Q_BB_D_HH_G_7_S >= 23.9103 ;
[_234] Q_BB_D_HH_G_8_E + Q_BB_D_HH_G_8_N + Q_BB_D_HH_G_8_S >= 12.3501 ;
[_235] Q_BB_D_HH_G_9_E + Q_BB_D_HH_G_9_N + Q_BB_D_HH_G_9_S >=
29.26000000000001 ;
[_236] Q_BB_D_HH_G_10_E + Q_BB_D_HH_G_10_N + Q_BB_D_HH_G_10_S >= 37.061
;
[_237] Q_BB_D_HH_G_11_E + Q_BB_D_HH_G_11_N + Q_BB_D_HH_G_11_S >= 40.95 ;
[_238] Q_BB_D_HH_G_12_E + Q_BB_D_HH_G_12_N + Q_BB_D_HH_G_12_S >= 1.8378
;
[_239] Q_BB_D_HH_G_13_E + Q_BB_D_HH_G_13_N + Q_BB_D_HH_G_13_S >= 41.46 ;
[_240] Q_BB_D_HH_G_14_E + Q_BB_D_HH_G_14_N + Q_BB_D_HH_G_14_S >=
34.12728 ;
[_241] Q_BB_D_HH_G_15_E + Q_BB_D_HH_G_15_N + Q_BB_D_HH_G_15_S >= 22.936
;
[_242] AT_DD_D_Z_DD1_E_1 <= 54 ;
[_243] AT_DD_D_Z_DD1_E_2 <= 54 ;
[_244] AT_DD_D_Z_DD1_N_1 <= 54 ;
[_245] AT_DD_D_Z_DD1_N_2 <= 54 ;
[_246] AT_DD_D_Z_DD1_S_1 <= 54 ;
[_247] AT_DD_D_Z_DD1_S_2 <= 54 ;
[_248] AT_DD_D_Z_DD2_E_1 <= 272 ;
[_249] AT_DD_D_Z_DD2_E_2 <= 204 ;
[_250] AT_DD_D_Z_DD2_N_1 <= 272 ;
[_251] AT_DD_D_Z_DD2_N_2 <= 204 ;
[_252] AT_DD_D_Z_DD2_S_1 <= 272 ;
[_253] AT_DD_D_Z_DD2_S_2 <= 204 ;
[_254] AT_DD_D_Z_DD3_E_1 <= 96 ;
[_255] AT_DD_D_Z_DD3_E_2 <= 48 ;
[_256] AT_DD_D_Z_DD3_N_1 <= 96 ;
[_257] AT_DD_D_Z_DD3_N_2 <= 48 ;
[_258] AT_DD_D_Z_DD3_S_1 <= 96 ;
[_259] AT_DD_D_Z_DD3_S_2 <= 48 ;
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[_260] AT_DD_D_Z_DD4_E_1 <= 252 ;
[_261] AT_DD_D_Z_DD4_E_2 <= 168 ;
[_262] AT_DD_D_Z_DD4_N_1 <= 252 ;
[_263] AT_DD_D_Z_DD4_N_2 <= 168 ;
[_264] AT_DD_D_Z_DD4_S_1 <= 252 ;
[_265] AT_DD_D_Z_DD4_S_2 <= 168 ;
[_266] AT_DD_D_Z_DD5_E_1 <= 204 ;
[_267] AT_DD_D_Z_DD5_E_2 <= 153 ;
[_268] AT_DD_D_Z_DD5_N_1 <= 204 ;
[_269] AT_DD_D_Z_DD5_N_2 <= 153 ;
[_270] AT_DD_D_Z_DD5_S_1 <= 204 ;
[_271] AT_DD_D_Z_DD5_S_2 <= 153 ;
[_272] AT_DD_D_Z_DD6_E_1 <= 12 ;
[_273] AT_DD_D_Z_DD6_E_2 <= 9 ;
[_274] AT_DD_D_Z_DD6_N_1 <= 12 ;
[_275] AT_DD_D_Z_DD6_N_2 <= 9 ;
[_276] AT_DD_D_Z_DD6_S_1 <= 12 ;
[_277] AT_DD_D_Z_DD6_S_2 <= 9 ;
[_278] AT_DD_D_Z_DD1_E_1 + AT_DD_D_Z_DD1_E_2 + AT_DD_D_Z_DD1_N_1 +
AT_DD_D_Z_DD1_N_2 + AT_DD_D_Z_DD1_S_1 + AT_DD_D_Z_DD1_S_2 <= 54 ;
[_279] AT_DD_D_Z_DD2_E_1 + AT_DD_D_Z_DD2_E_2 + AT_DD_D_Z_DD2_N_1 +
AT_DD_D_Z_DD2_N_2 + AT_DD_D_Z_DD2_S_1 + AT_DD_D_Z_DD2_S_2 <= 272 ;
[_280] AT_DD_D_Z_DD3_E_1 + AT_DD_D_Z_DD3_E_2 + AT_DD_D_Z_DD3_N_1 +
AT_DD_D_Z_DD3_N_2 + AT_DD_D_Z_DD3_S_1 + AT_DD_D_Z_DD3_S_2 <= 96 ;
[_281] AT_DD_D_Z_DD4_E_1 + AT_DD_D_Z_DD4_E_2 + AT_DD_D_Z_DD4_N_1 +
AT_DD_D_Z_DD4_N_2 + AT_DD_D_Z_DD4_S_1 + AT_DD_D_Z_DD4_S_2 <= 252 ;
[_282] AT_DD_D_Z_DD5_E_1 + AT_DD_D_Z_DD5_E_2 + AT_DD_D_Z_DD5_N_1 +
AT_DD_D_Z_DD5_N_2 + AT_DD_D_Z_DD5_S_1 + AT_DD_D_Z_DD5_S_2 <= 204 ;
[_283] AT_DD_D_Z_DD6_E_1 + AT_DD_D_Z_DD6_E_2 + AT_DD_D_Z_DD6_N_1 +
AT_DD_D_Z_DD6_N_2 + AT_DD_D_Z_DD6_S_1 + AT_DD_D_Z_DD6_S_2 <= 12 ;
[_284] AT_DD_D_Z_DD1_E_1 + AT_DD_D_Z_DD1_E_2 + AT_DD_D_Z_DD1_N_1 +
AT_DD_D_Z_DD1_N_2 + AT_DD_D_Z_DD1_S_1 + AT_DD_D_Z_DD1_S_2 >= 18 ;
[_285] AT_DD_D_Z_DD2_E_1 + AT_DD_D_Z_DD2_E_2 + AT_DD_D_Z_DD2_N_1 +
AT_DD_D_Z_DD2_N_2 + AT_DD_D_Z_DD2_S_1 + AT_DD_D_Z_DD2_S_2 >= 68 ;
[_286] AT_DD_D_Z_DD3_E_1 + AT_DD_D_Z_DD3_E_2 + AT_DD_D_Z_DD3_N_1 +
AT_DD_D_Z_DD3_N_2 + AT_DD_D_Z_DD3_S_1 + AT_DD_D_Z_DD3_S_2 >= 24 ;
[_287] AT_DD_D_Z_DD4_E_1 + AT_DD_D_Z_DD4_E_2 + AT_DD_D_Z_DD4_N_1 +
AT_DD_D_Z_DD4_N_2 + AT_DD_D_Z_DD4_S_1 + AT_DD_D_Z_DD4_S_2 >= 84 ;
[_288] AT_DD_D_Z_DD5_E_1 + AT_DD_D_Z_DD5_E_2 + AT_DD_D_Z_DD5_N_1 +
AT_DD_D_Z_DD5_N_2 + AT_DD_D_Z_DD5_S_1 + AT_DD_D_Z_DD5_S_2 >= 102 ;
[_289] AT_DD_D_Z_DD6_E_1 + AT_DD_D_Z_DD6_E_2 + AT_DD_D_Z_DD6_N_1 +
AT_DD_D_Z_DD6_N_2 + AT_DD_D_Z_DD6_S_1 + AT_DD_D_Z_DD6_S_2 >= 3 ;
[_290] DGHH_E_1 - Q_BB_D_HH_G_3_E - Q_BB_D_HH_G_4_E - Q_BB_D_HH_G_5_E -
Q_BB_D_HH_G_6_E - Q_BB_D_HH_G_7_E - Q_BB_D_HH_G_8_E - Q_BB_D_HH_G_10_E -
Q_BB_D_HH_G_12_E = 0 ;
[_291] DGHH_E_2 - Q_BB_D_HH_G_1_E - Q_BB_D_HH_G_2_E - Q_BB_D_HH_G_9_E -
Q_BB_D_HH_G_11_E - Q_BB_D_HH_G_13_E - Q_BB_D_HH_G_14_E -
Q_BB_D_HH_G_15_E = 0 ;
[_292] DGHH_N_1 - Q_BB_D_HH_G_1_N - Q_BB_D_HH_G_2_N - Q_BB_D_HH_G_3_N -
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Q_BB_D_HH_G_4_N - Q_BB_D_HH_G_5_N - Q_BB_D_HH_G_6_N - Q_BB_D_HH_G_7_N =
0 ;
[_293] DGHH_N_2 - Q_BB_D_HH_G_8_N - Q_BB_D_HH_G_9_N - Q_BB_D_HH_G_10_N -
Q_BB_D_HH_G_11_N - Q_BB_D_HH_G_12_N - Q_BB_D_HH_G_13_N -
Q_BB_D_HH_G_14_N - Q_BB_D_HH_G_15_N = 0 ;
[_294] DGHH_S_1 - Q_BB_D_HH_G_8_S - Q_BB_D_HH_G_9_S - Q_BB_D_HH_G_10_S -
Q_BB_D_HH_G_11_S - Q_BB_D_HH_G_12_S - Q_BB_D_HH_G_13_S -
Q_BB_D_HH_G_14_S = 0 ;
[_295] DGHH_S_2 - Q_BB_D_HH_G_1_S - Q_BB_D_HH_G_2_S - Q_BB_D_HH_G_3_S -
Q_BB_D_HH_G_4_S - Q_BB_D_HH_G_5_S - Q_BB_D_HH_G_6_S - Q_BB_D_HH_G_7_S -
Q_BB_D_HH_G_15_S = 0 ;
[_296] - DGDD_DD1_E_1 + Q_BB_D_DD_G_3_E_DD1 + Q_BB_D_DD_G_4_E_DD1 +
Q_BB_D_DD_G_5_E_DD1 + Q_BB_D_DD_G_6_E_DD1 + Q_BB_D_DD_G_7_E_DD1 +
Q_BB_D_DD_G_8_E_DD1 + Q_BB_D_DD_G_10_E_DD1 + Q_BB_D_DD_G_12_E_DD1 = 0 ;
[_297] - DGDD_DD2_E_1 + Q_BB_D_DD_G_3_E_DD2 + Q_BB_D_DD_G_4_E_DD2 +
Q_BB_D_DD_G_5_E_DD2 + Q_BB_D_DD_G_6_E_DD2 + Q_BB_D_DD_G_7_E_DD2 +
Q_BB_D_DD_G_8_E_DD2 + Q_BB_D_DD_G_10_E_DD2 + Q_BB_D_DD_G_12_E_DD2 = 0 ;
[_298] - DGDD_DD3_E_1 + Q_BB_D_DD_G_3_E_DD3 + Q_BB_D_DD_G_4_E_DD3 +
Q_BB_D_DD_G_5_E_DD3 + Q_BB_D_DD_G_6_E_DD3 + Q_BB_D_DD_G_7_E_DD3 +
Q_BB_D_DD_G_8_E_DD3 + Q_BB_D_DD_G_10_E_DD3 + Q_BB_D_DD_G_12_E_DD3 = 0 ;
[_299] - DGDD_DD4_E_1 + Q_BB_D_DD_G_3_E_DD4 + Q_BB_D_DD_G_4_E_DD4 +
Q_BB_D_DD_G_5_E_DD4 + Q_BB_D_DD_G_6_E_DD4 + Q_BB_D_DD_G_7_E_DD4 +
Q_BB_D_DD_G_8_E_DD4 + Q_BB_D_DD_G_10_E_DD4 + Q_BB_D_DD_G_12_E_DD4 = 0 ;
[_300] - DGDD_DD5_E_1 + Q_BB_D_DD_G_3_E_DD5 + Q_BB_D_DD_G_4_E_DD5 +
Q_BB_D_DD_G_5_E_DD5 + Q_BB_D_DD_G_6_E_DD5 + Q_BB_D_DD_G_7_E_DD5 +
Q_BB_D_DD_G_8_E_DD5 + Q_BB_D_DD_G_10_E_DD5 + Q_BB_D_DD_G_12_E_DD5 = 0 ;
[_301] - DGDD_DD6_E_1 + Q_BB_D_DD_G_3_E_DD6 + Q_BB_D_DD_G_4_E_DD6 +
Q_BB_D_DD_G_5_E_DD6 + Q_BB_D_DD_G_6_E_DD6 + Q_BB_D_DD_G_7_E_DD6 +
Q_BB_D_DD_G_8_E_DD6 + Q_BB_D_DD_G_10_E_DD6 + Q_BB_D_DD_G_12_E_DD6 = 0 ;
[_302] - DGDD_DD1_E_2 + Q_BB_D_DD_G_1_E_DD1 + Q_BB_D_DD_G_2_E_DD1 +
Q_BB_D_DD_G_9_E_DD1 + Q_BB_D_DD_G_11_E_DD1 + Q_BB_D_DD_G_13_E_DD1 +
Q_BB_D_DD_G_14_E_DD1 + Q_BB_D_DD_G_15_E_DD1 = 0 ;
[_303] - DGDD_DD2_E_2 + Q_BB_D_DD_G_1_E_DD2 + Q_BB_D_DD_G_2_E_DD2 +
Q_BB_D_DD_G_9_E_DD2 + Q_BB_D_DD_G_11_E_DD2 + Q_BB_D_DD_G_13_E_DD2 +
Q_BB_D_DD_G_14_E_DD2 + Q_BB_D_DD_G_15_E_DD2 = 0 ;
[_304] - DGDD_DD3_E_2 + Q_BB_D_DD_G_1_E_DD3 + Q_BB_D_DD_G_2_E_DD3 +
Q_BB_D_DD_G_9_E_DD3 + Q_BB_D_DD_G_11_E_DD3 + Q_BB_D_DD_G_13_E_DD3 +
Q_BB_D_DD_G_14_E_DD3 + Q_BB_D_DD_G_15_E_DD3 = 0 ;
[_305] - DGDD_DD4_E_2 + Q_BB_D_DD_G_1_E_DD4 + Q_BB_D_DD_G_2_E_DD4 +
Q_BB_D_DD_G_9_E_DD4 + Q_BB_D_DD_G_11_E_DD4 + Q_BB_D_DD_G_13_E_DD4 +
Q_BB_D_DD_G_14_E_DD4 + Q_BB_D_DD_G_15_E_DD4 = 0 ;
[_306] - DGDD_DD5_E_2 + Q_BB_D_DD_G_1_E_DD5 + Q_BB_D_DD_G_2_E_DD5 +
Q_BB_D_DD_G_9_E_DD5 + Q_BB_D_DD_G_11_E_DD5 + Q_BB_D_DD_G_13_E_DD5 +
Q_BB_D_DD_G_14_E_DD5 + Q_BB_D_DD_G_15_E_DD5 = 0 ;
[_307] - DGDD_DD6_E_2 + Q_BB_D_DD_G_1_E_DD6 + Q_BB_D_DD_G_2_E_DD6 +
Q_BB_D_DD_G_9_E_DD6 + Q_BB_D_DD_G_11_E_DD6 + Q_BB_D_DD_G_13_E_DD6 +
Q_BB_D_DD_G_14_E_DD6 + Q_BB_D_DD_G_15_E_DD6 = 0 ;
[_308] - DGDD_DD1_N_1 + Q_BB_D_DD_G_1_N_DD1 + Q_BB_D_DD_G_2_N_DD1 +
Q_BB_D_DD_G_3_N_DD1 + Q_BB_D_DD_G_4_N_DD1 + Q_BB_D_DD_G_5_N_DD1 +
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Q_BB_D_DD_G_6_N_DD1 + Q_BB_D_DD_G_7_N_DD1 = 0 ;
[_309] - DGDD_DD2_N_1 + Q_BB_D_DD_G_1_N_DD2 + Q_BB_D_DD_G_2_N_DD2 +
Q_BB_D_DD_G_3_N_DD2 + Q_BB_D_DD_G_4_N_DD2 + Q_BB_D_DD_G_5_N_DD2 +
Q_BB_D_DD_G_6_N_DD2 + Q_BB_D_DD_G_7_N_DD2 = 0 ;
[_310] - DGDD_DD3_N_1 + Q_BB_D_DD_G_1_N_DD3 + Q_BB_D_DD_G_2_N_DD3 +
Q_BB_D_DD_G_3_N_DD3 + Q_BB_D_DD_G_4_N_DD3 + Q_BB_D_DD_G_5_N_DD3 +
Q_BB_D_DD_G_6_N_DD3 + Q_BB_D_DD_G_7_N_DD3 = 0 ;
[_311] - DGDD_DD4_N_1 + Q_BB_D_DD_G_1_N_DD4 + Q_BB_D_DD_G_2_N_DD4 +
Q_BB_D_DD_G_3_N_DD4 + Q_BB_D_DD_G_4_N_DD4 + Q_BB_D_DD_G_5_N_DD4 +
Q_BB_D_DD_G_6_N_DD4 + Q_BB_D_DD_G_7_N_DD4 = 0 ;
[_312] - DGDD_DD5_N_1 + Q_BB_D_DD_G_1_N_DD5 + Q_BB_D_DD_G_2_N_DD5 +
Q_BB_D_DD_G_3_N_DD5 + Q_BB_D_DD_G_4_N_DD5 + Q_BB_D_DD_G_5_N_DD5 +
Q_BB_D_DD_G_6_N_DD5 + Q_BB_D_DD_G_7_N_DD5 = 0 ;
[_313] - DGDD_DD6_N_1 + Q_BB_D_DD_G_1_N_DD6 + Q_BB_D_DD_G_2_N_DD6 +
Q_BB_D_DD_G_3_N_DD6 + Q_BB_D_DD_G_4_N_DD6 + Q_BB_D_DD_G_5_N_DD6 +
Q_BB_D_DD_G_6_N_DD6 + Q_BB_D_DD_G_7_N_DD6 = 0 ;
[_314] - DGDD_DD1_N_2 + Q_BB_D_DD_G_8_N_DD1 + Q_BB_D_DD_G_9_N_DD1 +
Q_BB_D_DD_G_10_N_DD1 + Q_BB_D_DD_G_11_N_DD1 + Q_BB_D_DD_G_12_N_DD1 +
Q_BB_D_DD_G_13_N_DD1 + Q_BB_D_DD_G_14_N_DD1 + Q_BB_D_DD_G_15_N_DD1 = 0 ;
[_315] - DGDD_DD2_N_2 + Q_BB_D_DD_G_8_N_DD2 + Q_BB_D_DD_G_9_N_DD2 +
Q_BB_D_DD_G_10_N_DD2 + Q_BB_D_DD_G_11_N_DD2 + Q_BB_D_DD_G_12_N_DD2 +
Q_BB_D_DD_G_13_N_DD2 + Q_BB_D_DD_G_14_N_DD2 + Q_BB_D_DD_G_15_N_DD2 = 0 ;
[_316] - DGDD_DD3_N_2 + Q_BB_D_DD_G_8_N_DD3 + Q_BB_D_DD_G_9_N_DD3 +
Q_BB_D_DD_G_10_N_DD3 + Q_BB_D_DD_G_11_N_DD3 + Q_BB_D_DD_G_12_N_DD3 +
Q_BB_D_DD_G_13_N_DD3 + Q_BB_D_DD_G_14_N_DD3 + Q_BB_D_DD_G_15_N_DD3 = 0 ;
[_317] - DGDD_DD4_N_2 + Q_BB_D_DD_G_8_N_DD4 + Q_BB_D_DD_G_9_N_DD4 +
Q_BB_D_DD_G_10_N_DD4 + Q_BB_D_DD_G_11_N_DD4 + Q_BB_D_DD_G_12_N_DD4 +
Q_BB_D_DD_G_13_N_DD4 + Q_BB_D_DD_G_14_N_DD4 + Q_BB_D_DD_G_15_N_DD4 = 0 ;
[_318] - DGDD_DD5_N_2 + Q_BB_D_DD_G_8_N_DD5 + Q_BB_D_DD_G_9_N_DD5 +
Q_BB_D_DD_G_10_N_DD5 + Q_BB_D_DD_G_11_N_DD5 + Q_BB_D_DD_G_12_N_DD5 +
Q_BB_D_DD_G_13_N_DD5 + Q_BB_D_DD_G_14_N_DD5 + Q_BB_D_DD_G_15_N_DD5 = 0 ;
[_319] - DGDD_DD6_N_2 + Q_BB_D_DD_G_8_N_DD6 + Q_BB_D_DD_G_9_N_DD6 +
Q_BB_D_DD_G_10_N_DD6 + Q_BB_D_DD_G_11_N_DD6 + Q_BB_D_DD_G_12_N_DD6 +
Q_BB_D_DD_G_13_N_DD6 + Q_BB_D_DD_G_14_N_DD6 + Q_BB_D_DD_G_15_N_DD6 = 0 ;
[_320] - DGDD_DD1_S_1 + Q_BB_D_DD_G_8_S_DD1 + Q_BB_D_DD_G_9_S_DD1 +
Q_BB_D_DD_G_10_S_DD1 + Q_BB_D_DD_G_11_S_DD1 + Q_BB_D_DD_G_12_S_DD1 +
Q_BB_D_DD_G_13_S_DD1 + Q_BB_D_DD_G_14_S_DD1 = 0 ;
[_321] - DGDD_DD2_S_1 + Q_BB_D_DD_G_8_S_DD2 + Q_BB_D_DD_G_9_S_DD2 +
Q_BB_D_DD_G_10_S_DD2 + Q_BB_D_DD_G_11_S_DD2 + Q_BB_D_DD_G_12_S_DD2 +
Q_BB_D_DD_G_13_S_DD2 + Q_BB_D_DD_G_14_S_DD2 = 0 ;
[_322] - DGDD_DD3_S_1 + Q_BB_D_DD_G_8_S_DD3 + Q_BB_D_DD_G_9_S_DD3 +
Q_BB_D_DD_G_10_S_DD3 + Q_BB_D_DD_G_11_S_DD3 + Q_BB_D_DD_G_12_S_DD3 +
Q_BB_D_DD_G_13_S_DD3 + Q_BB_D_DD_G_14_S_DD3 = 0 ;
[_323] - DGDD_DD4_S_1 + Q_BB_D_DD_G_8_S_DD4 + Q_BB_D_DD_G_9_S_DD4 +
Q_BB_D_DD_G_10_S_DD4 + Q_BB_D_DD_G_11_S_DD4 + Q_BB_D_DD_G_12_S_DD4 +
Q_BB_D_DD_G_13_S_DD4 + Q_BB_D_DD_G_14_S_DD4 = 0 ;
[_324] - DGDD_DD5_S_1 + Q_BB_D_DD_G_8_S_DD5 + Q_BB_D_DD_G_9_S_DD5 +
Q_BB_D_DD_G_10_S_DD5 + Q_BB_D_DD_G_11_S_DD5 + Q_BB_D_DD_G_12_S_DD5 +
Q_BB_D_DD_G_13_S_DD5 + Q_BB_D_DD_G_14_S_DD5 = 0 ;
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[_325] - DGDD_DD6_S_1 + Q_BB_D_DD_G_8_S_DD6 + Q_BB_D_DD_G_9_S_DD6 +
Q_BB_D_DD_G_10_S_DD6 + Q_BB_D_DD_G_11_S_DD6 + Q_BB_D_DD_G_12_S_DD6 +
Q_BB_D_DD_G_13_S_DD6 + Q_BB_D_DD_G_14_S_DD6 = 0 ;
[_326] - DGDD_DD1_S_2 + Q_BB_D_DD_G_1_S_DD1 + Q_BB_D_DD_G_2_S_DD1 +
Q_BB_D_DD_G_3_S_DD1 + Q_BB_D_DD_G_4_S_DD1 + Q_BB_D_DD_G_5_S_DD1 +
Q_BB_D_DD_G_6_S_DD1 + Q_BB_D_DD_G_7_S_DD1 + Q_BB_D_DD_G_15_S_DD1 = 0 ;
[_327] - DGDD_DD2_S_2 + Q_BB_D_DD_G_1_S_DD2 + Q_BB_D_DD_G_2_S_DD2 +
Q_BB_D_DD_G_3_S_DD2 + Q_BB_D_DD_G_4_S_DD2 + Q_BB_D_DD_G_5_S_DD2 +
Q_BB_D_DD_G_6_S_DD2 + Q_BB_D_DD_G_7_S_DD2 + Q_BB_D_DD_G_15_S_DD2 = 0 ;
[_328] - DGDD_DD3_S_2 + Q_BB_D_DD_G_1_S_DD3 + Q_BB_D_DD_G_2_S_DD3 +
Q_BB_D_DD_G_3_S_DD3 + Q_BB_D_DD_G_4_S_DD3 + Q_BB_D_DD_G_5_S_DD3 +
Q_BB_D_DD_G_6_S_DD3 + Q_BB_D_DD_G_7_S_DD3 + Q_BB_D_DD_G_15_S_DD3 = 0 ;
[_329] - DGDD_DD4_S_2 + Q_BB_D_DD_G_1_S_DD4 + Q_BB_D_DD_G_2_S_DD4 +
Q_BB_D_DD_G_3_S_DD4 + Q_BB_D_DD_G_4_S_DD4 + Q_BB_D_DD_G_5_S_DD4 +
Q_BB_D_DD_G_6_S_DD4 + Q_BB_D_DD_G_7_S_DD4 + Q_BB_D_DD_G_15_S_DD4 = 0 ;
[_330] - DGDD_DD5_S_2 + Q_BB_D_DD_G_1_S_DD5 + Q_BB_D_DD_G_2_S_DD5 +
Q_BB_D_DD_G_3_S_DD5 + Q_BB_D_DD_G_4_S_DD5 + Q_BB_D_DD_G_5_S_DD5 +
Q_BB_D_DD_G_6_S_DD5 + Q_BB_D_DD_G_7_S_DD5 + Q_BB_D_DD_G_15_S_DD5 = 0 ;
[_331] - DGDD_DD6_S_2 + Q_BB_D_DD_G_1_S_DD6 + Q_BB_D_DD_G_2_S_DD6 +
Q_BB_D_DD_G_3_S_DD6 + Q_BB_D_DD_G_4_S_DD6 + Q_BB_D_DD_G_5_S_DD6 +
Q_BB_D_DD_G_6_S_DD6 + Q_BB_D_DD_G_7_S_DD6 + Q_BB_D_DD_G_15_S_DD6 = 0 ;
[_332] DSHH_E_1 - Q_BB_D_HH_S_3_E - Q_BB_D_HH_S_4_E - Q_BB_D_HH_S_5_E -
Q_BB_D_HH_S_6_E - Q_BB_D_HH_S_7_E - Q_BB_D_HH_S_8_E - Q_BB_D_HH_S_10_E -
Q_BB_D_HH_S_12_E = 0 ;
[_333] DSHH_E_2 - Q_BB_D_HH_S_1_E - Q_BB_D_HH_S_2_E - Q_BB_D_HH_S_9_E -
Q_BB_D_HH_S_11_E - Q_BB_D_HH_S_13_E - Q_BB_D_HH_S_14_E -
Q_BB_D_HH_S_15_E = 0 ;
[_334] DSHH_N_1 - Q_BB_D_HH_S_1_N - Q_BB_D_HH_S_2_N - Q_BB_D_HH_S_3_N -
Q_BB_D_HH_S_4_N - Q_BB_D_HH_S_5_N - Q_BB_D_HH_S_6_N - Q_BB_D_HH_S_7_N =
0 ;
[_335] DSHH_N_2 - Q_BB_D_HH_S_8_N - Q_BB_D_HH_S_9_N - Q_BB_D_HH_S_10_N -
Q_BB_D_HH_S_11_N - Q_BB_D_HH_S_12_N - Q_BB_D_HH_S_13_N -
Q_BB_D_HH_S_14_N - Q_BB_D_HH_S_15_N = 0 ;
[_336] DSHH_S_1 - Q_BB_D_HH_S_8_S - Q_BB_D_HH_S_9_S - Q_BB_D_HH_S_10_S -
Q_BB_D_HH_S_11_S - Q_BB_D_HH_S_12_S - Q_BB_D_HH_S_13_S -
Q_BB_D_HH_S_14_S = 0 ;
[_337] DSHH_S_2 - Q_BB_D_HH_S_1_S - Q_BB_D_HH_S_2_S - Q_BB_D_HH_S_3_S -
Q_BB_D_HH_S_4_S - Q_BB_D_HH_S_5_S - Q_BB_D_HH_S_6_S - Q_BB_D_HH_S_7_S -
Q_BB_D_HH_S_15_S = 0 ;
[_338] - 1.75 * AT_DD_D_Z_DD1_E_1 + Q_BB_D_DD_G_3_E_DD1 +
Q_BB_D_DD_G_4_E_DD1 + Q_BB_D_DD_G_5_E_DD1 + Q_BB_D_DD_G_6_E_DD1 +
Q_BB_D_DD_G_7_E_DD1 + Q_BB_D_DD_G_8_E_DD1 + Q_BB_D_DD_G_10_E_DD1 +
Q_BB_D_DD_G_12_E_DD1 = 0 ;
[_339] - 2 * AT_DD_D_Z_DD2_E_1 + Q_BB_D_DD_G_3_E_DD2 +
Q_BB_D_DD_G_4_E_DD2 + Q_BB_D_DD_G_5_E_DD2 + Q_BB_D_DD_G_6_E_DD2 +
Q_BB_D_DD_G_7_E_DD2 + Q_BB_D_DD_G_8_E_DD2 + Q_BB_D_DD_G_10_E_DD2 +
Q_BB_D_DD_G_12_E_DD2 = 0 ;
[_340] - 7 * AT_DD_D_Z_DD3_E_1 + Q_BB_D_DD_G_3_E_DD3 +
Q_BB_D_DD_G_4_E_DD3 + Q_BB_D_DD_G_5_E_DD3 + Q_BB_D_DD_G_6_E_DD3 +
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Q_BB_D_DD_G_7_E_DD3 + Q_BB_D_DD_G_8_E_DD3 + Q_BB_D_DD_G_10_E_DD3 +
Q_BB_D_DD_G_12_E_DD3 = 0 ;
[_341] - 9 * AT_DD_D_Z_DD4_E_1 + Q_BB_D_DD_G_3_E_DD4 +
Q_BB_D_DD_G_4_E_DD4 + Q_BB_D_DD_G_5_E_DD4 + Q_BB_D_DD_G_6_E_DD4 +
Q_BB_D_DD_G_7_E_DD4 + Q_BB_D_DD_G_8_E_DD4 + Q_BB_D_DD_G_10_E_DD4 +
Q_BB_D_DD_G_12_E_DD4 = 0 ;
[_342] - 10 * AT_DD_D_Z_DD5_E_1 + Q_BB_D_DD_G_3_E_DD5 +
Q_BB_D_DD_G_4_E_DD5 + Q_BB_D_DD_G_5_E_DD5 + Q_BB_D_DD_G_6_E_DD5 +
Q_BB_D_DD_G_7_E_DD5 + Q_BB_D_DD_G_8_E_DD5 + Q_BB_D_DD_G_10_E_DD5 +
Q_BB_D_DD_G_12_E_DD5 = 0 ;
[_343] - 7 * AT_DD_D_Z_DD6_E_1 + Q_BB_D_DD_G_3_E_DD6 +
Q_BB_D_DD_G_4_E_DD6 + Q_BB_D_DD_G_5_E_DD6 + Q_BB_D_DD_G_6_E_DD6 +
Q_BB_D_DD_G_7_E_DD6 + Q_BB_D_DD_G_8_E_DD6 + Q_BB_D_DD_G_10_E_DD6 +
Q_BB_D_DD_G_12_E_DD6 = 0 ;
[_344] - 1.75 * AT_DD_D_Z_DD1_E_2 + Q_BB_D_DD_G_1_E_DD1 +
Q_BB_D_DD_G_2_E_DD1 + Q_BB_D_DD_G_9_E_DD1 + Q_BB_D_DD_G_11_E_DD1 +
Q_BB_D_DD_G_13_E_DD1 + Q_BB_D_DD_G_14_E_DD1 + Q_BB_D_DD_G_15_E_DD1 = 0 ;
[_345] - 2 * AT_DD_D_Z_DD2_E_2 + Q_BB_D_DD_G_1_E_DD2 +
Q_BB_D_DD_G_2_E_DD2 + Q_BB_D_DD_G_9_E_DD2 + Q_BB_D_DD_G_11_E_DD2 +
Q_BB_D_DD_G_13_E_DD2 + Q_BB_D_DD_G_14_E_DD2 + Q_BB_D_DD_G_15_E_DD2 = 0 ;
[_346] - 7 * AT_DD_D_Z_DD3_E_2 + Q_BB_D_DD_G_1_E_DD3 +
Q_BB_D_DD_G_2_E_DD3 + Q_BB_D_DD_G_9_E_DD3 + Q_BB_D_DD_G_11_E_DD3 +
Q_BB_D_DD_G_13_E_DD3 + Q_BB_D_DD_G_14_E_DD3 + Q_BB_D_DD_G_15_E_DD3 = 0 ;
[_347] - 9 * AT_DD_D_Z_DD4_E_2 + Q_BB_D_DD_G_1_E_DD4 +
Q_BB_D_DD_G_2_E_DD4 + Q_BB_D_DD_G_9_E_DD4 + Q_BB_D_DD_G_11_E_DD4 +
Q_BB_D_DD_G_13_E_DD4 + Q_BB_D_DD_G_14_E_DD4 + Q_BB_D_DD_G_15_E_DD4 = 0 ;
[_348] - 10 * AT_DD_D_Z_DD5_E_2 + Q_BB_D_DD_G_1_E_DD5 +
Q_BB_D_DD_G_2_E_DD5 + Q_BB_D_DD_G_9_E_DD5 + Q_BB_D_DD_G_11_E_DD5 +
Q_BB_D_DD_G_13_E_DD5 + Q_BB_D_DD_G_14_E_DD5 + Q_BB_D_DD_G_15_E_DD5 = 0 ;
[_349] - 7 * AT_DD_D_Z_DD6_E_2 + Q_BB_D_DD_G_1_E_DD6 +
Q_BB_D_DD_G_2_E_DD6 + Q_BB_D_DD_G_9_E_DD6 + Q_BB_D_DD_G_11_E_DD6 +
Q_BB_D_DD_G_13_E_DD6 + Q_BB_D_DD_G_14_E_DD6 + Q_BB_D_DD_G_15_E_DD6 = 0 ;
[_350] - 1.75 * AT_DD_D_Z_DD1_N_1 + Q_BB_D_DD_G_1_N_DD1 +
Q_BB_D_DD_G_2_N_DD1 + Q_BB_D_DD_G_3_N_DD1 + Q_BB_D_DD_G_4_N_DD1 +
Q_BB_D_DD_G_5_N_DD1 + Q_BB_D_DD_G_6_N_DD1 + Q_BB_D_DD_G_7_N_DD1 = 0 ;
[_351] - 2 * AT_DD_D_Z_DD2_N_1 + Q_BB_D_DD_G_1_N_DD2 +
Q_BB_D_DD_G_2_N_DD2 + Q_BB_D_DD_G_3_N_DD2 + Q_BB_D_DD_G_4_N_DD2 +
Q_BB_D_DD_G_5_N_DD2 + Q_BB_D_DD_G_6_N_DD2 + Q_BB_D_DD_G_7_N_DD2 = 0 ;
[_352] - 7 * AT_DD_D_Z_DD3_N_1 + Q_BB_D_DD_G_1_N_DD3 +
Q_BB_D_DD_G_2_N_DD3 + Q_BB_D_DD_G_3_N_DD3 + Q_BB_D_DD_G_4_N_DD3 +
Q_BB_D_DD_G_5_N_DD3 + Q_BB_D_DD_G_6_N_DD3 + Q_BB_D_DD_G_7_N_DD3 = 0 ;
[_353] - 9 * AT_DD_D_Z_DD4_N_1 + Q_BB_D_DD_G_1_N_DD4 +
Q_BB_D_DD_G_2_N_DD4 + Q_BB_D_DD_G_3_N_DD4 + Q_BB_D_DD_G_4_N_DD4 +
Q_BB_D_DD_G_5_N_DD4 + Q_BB_D_DD_G_6_N_DD4 + Q_BB_D_DD_G_7_N_DD4 = 0 ;
[_354] - 10 * AT_DD_D_Z_DD5_N_1 + Q_BB_D_DD_G_1_N_DD5 +
Q_BB_D_DD_G_2_N_DD5 + Q_BB_D_DD_G_3_N_DD5 + Q_BB_D_DD_G_4_N_DD5 +
Q_BB_D_DD_G_5_N_DD5 + Q_BB_D_DD_G_6_N_DD5 + Q_BB_D_DD_G_7_N_DD5 = 0 ;
[_355] - 7 * AT_DD_D_Z_DD6_N_1 + Q_BB_D_DD_G_1_N_DD6 +
Q_BB_D_DD_G_2_N_DD6 + Q_BB_D_DD_G_3_N_DD6 + Q_BB_D_DD_G_4_N_DD6 +
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Q_BB_D_DD_G_5_N_DD6 + Q_BB_D_DD_G_6_N_DD6 + Q_BB_D_DD_G_7_N_DD6 = 0 ;
[_356] - 1.75 * AT_DD_D_Z_DD1_N_2 + Q_BB_D_DD_G_8_N_DD1 +
Q_BB_D_DD_G_9_N_DD1 + Q_BB_D_DD_G_10_N_DD1 + Q_BB_D_DD_G_11_N_DD1 +
Q_BB_D_DD_G_12_N_DD1 + Q_BB_D_DD_G_13_N_DD1 + Q_BB_D_DD_G_14_N_DD1 +
Q_BB_D_DD_G_15_N_DD1 = 0 ;
[_357] - 2 * AT_DD_D_Z_DD2_N_2 + Q_BB_D_DD_G_8_N_DD2 +
Q_BB_D_DD_G_9_N_DD2 + Q_BB_D_DD_G_10_N_DD2 + Q_BB_D_DD_G_11_N_DD2 +
Q_BB_D_DD_G_12_N_DD2 + Q_BB_D_DD_G_13_N_DD2 + Q_BB_D_DD_G_14_N_DD2 +
Q_BB_D_DD_G_15_N_DD2 = 0 ;
[_358] - 7 * AT_DD_D_Z_DD3_N_2 + Q_BB_D_DD_G_8_N_DD3 +
Q_BB_D_DD_G_9_N_DD3 + Q_BB_D_DD_G_10_N_DD3 + Q_BB_D_DD_G_11_N_DD3 +
Q_BB_D_DD_G_12_N_DD3 + Q_BB_D_DD_G_13_N_DD3 + Q_BB_D_DD_G_14_N_DD3 +
Q_BB_D_DD_G_15_N_DD3 = 0 ;
[_359] - 9 * AT_DD_D_Z_DD4_N_2 + Q_BB_D_DD_G_8_N_DD4 +
Q_BB_D_DD_G_9_N_DD4 + Q_BB_D_DD_G_10_N_DD4 + Q_BB_D_DD_G_11_N_DD4 +
Q_BB_D_DD_G_12_N_DD4 + Q_BB_D_DD_G_13_N_DD4 + Q_BB_D_DD_G_14_N_DD4 +
Q_BB_D_DD_G_15_N_DD4 = 0 ;
[_360] - 10 * AT_DD_D_Z_DD5_N_2 + Q_BB_D_DD_G_8_N_DD5 +
Q_BB_D_DD_G_9_N_DD5 + Q_BB_D_DD_G_10_N_DD5 + Q_BB_D_DD_G_11_N_DD5 +
Q_BB_D_DD_G_12_N_DD5 + Q_BB_D_DD_G_13_N_DD5 + Q_BB_D_DD_G_14_N_DD5 +
Q_BB_D_DD_G_15_N_DD5 = 0 ;
[_361] - 7 * AT_DD_D_Z_DD6_N_2 + Q_BB_D_DD_G_8_N_DD6 +
Q_BB_D_DD_G_9_N_DD6 + Q_BB_D_DD_G_10_N_DD6 + Q_BB_D_DD_G_11_N_DD6 +
Q_BB_D_DD_G_12_N_DD6 + Q_BB_D_DD_G_13_N_DD6 + Q_BB_D_DD_G_14_N_DD6 +
Q_BB_D_DD_G_15_N_DD6 = 0 ;
[_362] - 1.75 * AT_DD_D_Z_DD1_S_1 + Q_BB_D_DD_G_8_S_DD1 +
Q_BB_D_DD_G_9_S_DD1 + Q_BB_D_DD_G_10_S_DD1 + Q_BB_D_DD_G_11_S_DD1 +
Q_BB_D_DD_G_12_S_DD1 + Q_BB_D_DD_G_13_S_DD1 + Q_BB_D_DD_G_14_S_DD1 = 0 ;
[_363] - 2 * AT_DD_D_Z_DD2_S_1 + Q_BB_D_DD_G_8_S_DD2 +
Q_BB_D_DD_G_9_S_DD2 + Q_BB_D_DD_G_10_S_DD2 + Q_BB_D_DD_G_11_S_DD2 +
Q_BB_D_DD_G_12_S_DD2 + Q_BB_D_DD_G_13_S_DD2 + Q_BB_D_DD_G_14_S_DD2 = 0 ;
[_364] - 7 * AT_DD_D_Z_DD3_S_1 + Q_BB_D_DD_G_8_S_DD3 +
Q_BB_D_DD_G_9_S_DD3 + Q_BB_D_DD_G_10_S_DD3 + Q_BB_D_DD_G_11_S_DD3 +
Q_BB_D_DD_G_12_S_DD3 + Q_BB_D_DD_G_13_S_DD3 + Q_BB_D_DD_G_14_S_DD3 = 0 ;
[_365] - 9 * AT_DD_D_Z_DD4_S_1 + Q_BB_D_DD_G_8_S_DD4 +
Q_BB_D_DD_G_9_S_DD4 + Q_BB_D_DD_G_10_S_DD4 + Q_BB_D_DD_G_11_S_DD4 +
Q_BB_D_DD_G_12_S_DD4 + Q_BB_D_DD_G_13_S_DD4 + Q_BB_D_DD_G_14_S_DD4 = 0 ;
[_366] - 10 * AT_DD_D_Z_DD5_S_1 + Q_BB_D_DD_G_8_S_DD5 +
Q_BB_D_DD_G_9_S_DD5 + Q_BB_D_DD_G_10_S_DD5 + Q_BB_D_DD_G_11_S_DD5 +
Q_BB_D_DD_G_12_S_DD5 + Q_BB_D_DD_G_13_S_DD5 + Q_BB_D_DD_G_14_S_DD5 = 0 ;
[_367] - 7 * AT_DD_D_Z_DD6_S_1 + Q_BB_D_DD_G_8_S_DD6 +
Q_BB_D_DD_G_9_S_DD6 + Q_BB_D_DD_G_10_S_DD6 + Q_BB_D_DD_G_11_S_DD6 +
Q_BB_D_DD_G_12_S_DD6 + Q_BB_D_DD_G_13_S_DD6 + Q_BB_D_DD_G_14_S_DD6 = 0 ;
[_368] - 1.75 * AT_DD_D_Z_DD1_S_2 + Q_BB_D_DD_G_1_S_DD1 +
Q_BB_D_DD_G_2_S_DD1 + Q_BB_D_DD_G_3_S_DD1 + Q_BB_D_DD_G_4_S_DD1 +
Q_BB_D_DD_G_5_S_DD1 + Q_BB_D_DD_G_6_S_DD1 + Q_BB_D_DD_G_7_S_DD1 +
Q_BB_D_DD_G_15_S_DD1 = 0 ;
[_369] - 2 * AT_DD_D_Z_DD2_S_2 + Q_BB_D_DD_G_1_S_DD2 +
Q_BB_D_DD_G_2_S_DD2 + Q_BB_D_DD_G_3_S_DD2 + Q_BB_D_DD_G_4_S_DD2 +
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Q_BB_D_DD_G_5_S_DD2 + Q_BB_D_DD_G_6_S_DD2 + Q_BB_D_DD_G_7_S_DD2 +
Q_BB_D_DD_G_15_S_DD2 = 0 ;
[_370] - 7 * AT_DD_D_Z_DD3_S_2 + Q_BB_D_DD_G_1_S_DD3 +
Q_BB_D_DD_G_2_S_DD3 + Q_BB_D_DD_G_3_S_DD3 + Q_BB_D_DD_G_4_S_DD3 +
Q_BB_D_DD_G_5_S_DD3 + Q_BB_D_DD_G_6_S_DD3 + Q_BB_D_DD_G_7_S_DD3 +
Q_BB_D_DD_G_15_S_DD3 = 0 ;
[_371] - 9 * AT_DD_D_Z_DD4_S_2 + Q_BB_D_DD_G_1_S_DD4 +
Q_BB_D_DD_G_2_S_DD4 + Q_BB_D_DD_G_3_S_DD4 + Q_BB_D_DD_G_4_S_DD4 +
Q_BB_D_DD_G_5_S_DD4 + Q_BB_D_DD_G_6_S_DD4 + Q_BB_D_DD_G_7_S_DD4 +
Q_BB_D_DD_G_15_S_DD4 = 0 ;
[_372] - 10 * AT_DD_D_Z_DD5_S_2 + Q_BB_D_DD_G_1_S_DD5 +
Q_BB_D_DD_G_2_S_DD5 + Q_BB_D_DD_G_3_S_DD5 + Q_BB_D_DD_G_4_S_DD5 +
Q_BB_D_DD_G_5_S_DD5 + Q_BB_D_DD_G_6_S_DD5 + Q_BB_D_DD_G_7_S_DD5 +
Q_BB_D_DD_G_15_S_DD5 = 0 ;
[_373] - 7 * AT_DD_D_Z_DD6_S_2 + Q_BB_D_DD_G_1_S_DD6 +
Q_BB_D_DD_G_2_S_DD6 + Q_BB_D_DD_G_3_S_DD6 + Q_BB_D_DD_G_4_S_DD6 +
Q_BB_D_DD_G_5_S_DD6 + Q_BB_D_DD_G_6_S_DD6 + Q_BB_D_DD_G_7_S_DD6 +
Q_BB_D_DD_G_15_S_DD6 = 0 ;
[_374] - 7 * AT_HHG_D_Z_E_1 + Q_BB_D_HH_G_3_E + Q_BB_D_HH_G_4_E +
Q_BB_D_HH_G_5_E + Q_BB_D_HH_G_6_E + Q_BB_D_HH_G_7_E + Q_BB_D_HH_G_8_E +
Q_BB_D_HH_G_10_E + Q_BB_D_HH_G_12_E = 0 ;
[_375] - 7 * AT_HHG_D_Z_E_2 + Q_BB_D_HH_G_1_E + Q_BB_D_HH_G_2_E +
Q_BB_D_HH_G_9_E + Q_BB_D_HH_G_11_E + Q_BB_D_HH_G_13_E + Q_BB_D_HH_G_14_E
+ Q_BB_D_HH_G_15_E = 0 ;
[_376] - 7 * AT_HHG_D_Z_N_1 + Q_BB_D_HH_G_1_N + Q_BB_D_HH_G_2_N +
Q_BB_D_HH_G_3_N + Q_BB_D_HH_G_4_N + Q_BB_D_HH_G_5_N + Q_BB_D_HH_G_6_N +
Q_BB_D_HH_G_7_N = 0 ;
[_377] - 7 * AT_HHG_D_Z_N_2 + Q_BB_D_HH_G_8_N + Q_BB_D_HH_G_9_N +
Q_BB_D_HH_G_10_N + Q_BB_D_HH_G_11_N + Q_BB_D_HH_G_12_N +
Q_BB_D_HH_G_13_N + Q_BB_D_HH_G_14_N + Q_BB_D_HH_G_15_N = 0 ;
[_378] - 7 * AT_HHG_D_Z_S_1 + Q_BB_D_HH_G_8_S + Q_BB_D_HH_G_9_S +
Q_BB_D_HH_G_10_S + Q_BB_D_HH_G_11_S + Q_BB_D_HH_G_12_S +
Q_BB_D_HH_G_13_S + Q_BB_D_HH_G_14_S = 0 ;
[_379] - 7 * AT_HHG_D_Z_S_2 + Q_BB_D_HH_G_1_S + Q_BB_D_HH_G_2_S +
Q_BB_D_HH_G_3_S + Q_BB_D_HH_G_4_S + Q_BB_D_HH_G_5_S + Q_BB_D_HH_G_6_S +
Q_BB_D_HH_G_7_S + Q_BB_D_HH_G_15_S = 0 ;
[_380] - 9 * AT_HHS_D_Z_E_1 + Q_BB_D_HH_S_3_E + Q_BB_D_HH_S_4_E +
Q_BB_D_HH_S_5_E + Q_BB_D_HH_S_6_E + Q_BB_D_HH_S_7_E + Q_BB_D_HH_S_8_E +
Q_BB_D_HH_S_10_E + Q_BB_D_HH_S_12_E = 0 ;
[_381] - 9 * AT_HHS_D_Z_E_2 + Q_BB_D_HH_S_1_E + Q_BB_D_HH_S_2_E +
Q_BB_D_HH_S_9_E + Q_BB_D_HH_S_11_E + Q_BB_D_HH_S_13_E + Q_BB_D_HH_S_14_E
+ Q_BB_D_HH_S_15_E = 0 ;
[_382] - 9 * AT_HHS_D_Z_N_1 + Q_BB_D_HH_S_1_N + Q_BB_D_HH_S_2_N +
Q_BB_D_HH_S_3_N + Q_BB_D_HH_S_4_N + Q_BB_D_HH_S_5_N + Q_BB_D_HH_S_6_N +
Q_BB_D_HH_S_7_N = 0 ;
[_383] - 9 * AT_HHS_D_Z_N_2 + Q_BB_D_HH_S_8_N + Q_BB_D_HH_S_9_N +
Q_BB_D_HH_S_10_N + Q_BB_D_HH_S_11_N + Q_BB_D_HH_S_12_N +
Q_BB_D_HH_S_13_N + Q_BB_D_HH_S_14_N + Q_BB_D_HH_S_15_N = 0 ;
[_384] - 9 * AT_HHS_D_Z_S_1 + Q_BB_D_HH_S_8_S + Q_BB_D_HH_S_9_S +
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Q_BB_D_HH_S_10_S + Q_BB_D_HH_S_11_S + Q_BB_D_HH_S_12_S +
Q_BB_D_HH_S_13_S + Q_BB_D_HH_S_14_S = 0 ;
[_385] - 9 * AT_HHS_D_Z_S_2 + Q_BB_D_HH_S_1_S + Q_BB_D_HH_S_2_S +
Q_BB_D_HH_S_3_S + Q_BB_D_HH_S_4_S + Q_BB_D_HH_S_5_S + Q_BB_D_HH_S_6_S +
Q_BB_D_HH_S_7_S + Q_BB_D_HH_S_15_S = 0 ;
[_386] Q_BB_D_HH_G_1_E + Q_BB_D_HH_G_2_E + Q_BB_D_HH_G_3_E +
Q_BB_D_HH_G_4_E + Q_BB_D_HH_G_5_E + Q_BB_D_HH_G_6_E + Q_BB_D_HH_G_7_E +
Q_BB_D_HH_G_8_E + Q_BB_D_HH_G_9_E + Q_BB_D_HH_G_10_E + Q_BB_D_HH_G_11_E
+ Q_BB_D_HH_G_12_E + Q_BB_D_HH_G_13_E + Q_BB_D_HH_G_14_E +
Q_BB_D_HH_G_15_E + Q_BB_D_DD_G_1_E_DD1 + Q_BB_D_DD_G_1_E_DD2 +
Q_BB_D_DD_G_1_E_DD3 + Q_BB_D_DD_G_1_E_DD4 + Q_BB_D_DD_G_1_E_DD5 +
Q_BB_D_DD_G_1_E_DD6 + Q_BB_D_DD_G_2_E_DD1 + Q_BB_D_DD_G_2_E_DD2 +
Q_BB_D_DD_G_2_E_DD3 + Q_BB_D_DD_G_2_E_DD4 + Q_BB_D_DD_G_2_E_DD5 +
Q_BB_D_DD_G_2_E_DD6 + Q_BB_D_DD_G_3_E_DD1 + Q_BB_D_DD_G_3_E_DD2 +
Q_BB_D_DD_G_3_E_DD3 + Q_BB_D_DD_G_3_E_DD4 + Q_BB_D_DD_G_3_E_DD5 +
Q_BB_D_DD_G_3_E_DD6 + Q_BB_D_DD_G_4_E_DD1 + Q_BB_D_DD_G_4_E_DD2 +
Q_BB_D_DD_G_4_E_DD3 + Q_BB_D_DD_G_4_E_DD4 + Q_BB_D_DD_G_4_E_DD5 +
Q_BB_D_DD_G_4_E_DD6 + Q_BB_D_DD_G_5_E_DD1 + Q_BB_D_DD_G_5_E_DD2 +
Q_BB_D_DD_G_5_E_DD3 + Q_BB_D_DD_G_5_E_DD4 + Q_BB_D_DD_G_5_E_DD5 +
Q_BB_D_DD_G_5_E_DD6 + Q_BB_D_DD_G_6_E_DD1 + Q_BB_D_DD_G_6_E_DD2 +
Q_BB_D_DD_G_6_E_DD3 + Q_BB_D_DD_G_6_E_DD4 + Q_BB_D_DD_G_6_E_DD5 +
Q_BB_D_DD_G_6_E_DD6 + Q_BB_D_DD_G_7_E_DD1 + Q_BB_D_DD_G_7_E_DD2 +
Q_BB_D_DD_G_7_E_DD3 + Q_BB_D_DD_G_7_E_DD4 + Q_BB_D_DD_G_7_E_DD5 +
Q_BB_D_DD_G_7_E_DD6 + Q_BB_D_DD_G_8_E_DD1 + Q_BB_D_DD_G_8_E_DD2 +
Q_BB_D_DD_G_8_E_DD3 + Q_BB_D_DD_G_8_E_DD4 + Q_BB_D_DD_G_8_E_DD5 +
Q_BB_D_DD_G_8_E_DD6 + Q_BB_D_DD_G_9_E_DD1 + Q_BB_D_DD_G_9_E_DD2 +
Q_BB_D_DD_G_9_E_DD3 + Q_BB_D_DD_G_9_E_DD4 + Q_BB_D_DD_G_9_E_DD5 +
Q_BB_D_DD_G_9_E_DD6 + Q_BB_D_DD_G_10_E_DD1 + Q_BB_D_DD_G_10_E_DD2 +
Q_BB_D_DD_G_10_E_DD3 + Q_BB_D_DD_G_10_E_DD4 + Q_BB_D_DD_G_10_E_DD5 +
Q_BB_D_DD_G_10_E_DD6 + Q_BB_D_DD_G_11_E_DD1 + Q_BB_D_DD_G_11_E_DD2 +
Q_BB_D_DD_G_11_E_DD3 + Q_BB_D_DD_G_11_E_DD4 + Q_BB_D_DD_G_11_E_DD5 +
Q_BB_D_DD_G_11_E_DD6 + Q_BB_D_DD_G_12_E_DD1 + Q_BB_D_DD_G_12_E_DD2 +
Q_BB_D_DD_G_12_E_DD3 + Q_BB_D_DD_G_12_E_DD4 + Q_BB_D_DD_G_12_E_DD5 +
Q_BB_D_DD_G_12_E_DD6 + Q_BB_D_DD_G_13_E_DD1 + Q_BB_D_DD_G_13_E_DD2 +
Q_BB_D_DD_G_13_E_DD3 + Q_BB_D_DD_G_13_E_DD4 + Q_BB_D_DD_G_13_E_DD5 +
Q_BB_D_DD_G_13_E_DD6 + Q_BB_D_DD_G_14_E_DD1 + Q_BB_D_DD_G_14_E_DD2 +
Q_BB_D_DD_G_14_E_DD3 + Q_BB_D_DD_G_14_E_DD4 + Q_BB_D_DD_G_14_E_DD5 +
Q_BB_D_DD_G_14_E_DD6 + Q_BB_D_DD_G_15_E_DD1 + Q_BB_D_DD_G_15_E_DD2 +
Q_BB_D_DD_G_15_E_DD3 + Q_BB_D_DD_G_15_E_DD4 + Q_BB_D_DD_G_15_E_DD5 +
Q_BB_D_DD_G_15_E_DD6 - SGF_E = 0 ;
[_387] Q_BB_D_HH_G_1_N + Q_BB_D_HH_G_2_N + Q_BB_D_HH_G_3_N +
Q_BB_D_HH_G_4_N + Q_BB_D_HH_G_5_N + Q_BB_D_HH_G_6_N + Q_BB_D_HH_G_7_N +
Q_BB_D_HH_G_8_N + Q_BB_D_HH_G_9_N + Q_BB_D_HH_G_10_N + Q_BB_D_HH_G_11_N
+ Q_BB_D_HH_G_12_N + Q_BB_D_HH_G_13_N + Q_BB_D_HH_G_14_N +
Q_BB_D_HH_G_15_N + Q_BB_D_DD_G_1_N_DD1 + Q_BB_D_DD_G_1_N_DD2 +
Q_BB_D_DD_G_1_N_DD3 + Q_BB_D_DD_G_1_N_DD4 + Q_BB_D_DD_G_1_N_DD5 +
Q_BB_D_DD_G_1_N_DD6 + Q_BB_D_DD_G_2_N_DD1 + Q_BB_D_DD_G_2_N_DD2 +
Q_BB_D_DD_G_2_N_DD3 + Q_BB_D_DD_G_2_N_DD4 + Q_BB_D_DD_G_2_N_DD5 +
Q_BB_D_DD_G_2_N_DD6 + Q_BB_D_DD_G_3_N_DD1 + Q_BB_D_DD_G_3_N_DD2 +
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Q_BB_D_DD_G_3_N_DD3 + Q_BB_D_DD_G_3_N_DD4 + Q_BB_D_DD_G_3_N_DD5 +
Q_BB_D_DD_G_3_N_DD6 + Q_BB_D_DD_G_4_N_DD1 + Q_BB_D_DD_G_4_N_DD2 +
Q_BB_D_DD_G_4_N_DD3 + Q_BB_D_DD_G_4_N_DD4 + Q_BB_D_DD_G_4_N_DD5 +
Q_BB_D_DD_G_4_N_DD6 + Q_BB_D_DD_G_5_N_DD1 + Q_BB_D_DD_G_5_N_DD2 +
Q_BB_D_DD_G_5_N_DD3 + Q_BB_D_DD_G_5_N_DD4 + Q_BB_D_DD_G_5_N_DD5 +
Q_BB_D_DD_G_5_N_DD6 + Q_BB_D_DD_G_6_N_DD1 + Q_BB_D_DD_G_6_N_DD2 +
Q_BB_D_DD_G_6_N_DD3 + Q_BB_D_DD_G_6_N_DD4 + Q_BB_D_DD_G_6_N_DD5 +
Q_BB_D_DD_G_6_N_DD6 + Q_BB_D_DD_G_7_N_DD1 + Q_BB_D_DD_G_7_N_DD2 +
Q_BB_D_DD_G_7_N_DD3 + Q_BB_D_DD_G_7_N_DD4 + Q_BB_D_DD_G_7_N_DD5 +
Q_BB_D_DD_G_7_N_DD6 + Q_BB_D_DD_G_8_N_DD1 + Q_BB_D_DD_G_8_N_DD2 +
Q_BB_D_DD_G_8_N_DD3 + Q_BB_D_DD_G_8_N_DD4 + Q_BB_D_DD_G_8_N_DD5 +
Q_BB_D_DD_G_8_N_DD6 + Q_BB_D_DD_G_9_N_DD1 + Q_BB_D_DD_G_9_N_DD2 +
Q_BB_D_DD_G_9_N_DD3 + Q_BB_D_DD_G_9_N_DD4 + Q_BB_D_DD_G_9_N_DD5 +
Q_BB_D_DD_G_9_N_DD6 + Q_BB_D_DD_G_10_N_DD1 + Q_BB_D_DD_G_10_N_DD2 +
Q_BB_D_DD_G_10_N_DD3 + Q_BB_D_DD_G_10_N_DD4 + Q_BB_D_DD_G_10_N_DD5 +
Q_BB_D_DD_G_10_N_DD6 + Q_BB_D_DD_G_11_N_DD1 + Q_BB_D_DD_G_11_N_DD2 +
Q_BB_D_DD_G_11_N_DD3 + Q_BB_D_DD_G_11_N_DD4 + Q_BB_D_DD_G_11_N_DD5 +
Q_BB_D_DD_G_11_N_DD6 + Q_BB_D_DD_G_12_N_DD1 + Q_BB_D_DD_G_12_N_DD2 +
Q_BB_D_DD_G_12_N_DD3 + Q_BB_D_DD_G_12_N_DD4 + Q_BB_D_DD_G_12_N_DD5 +
Q_BB_D_DD_G_12_N_DD6 + Q_BB_D_DD_G_13_N_DD1 + Q_BB_D_DD_G_13_N_DD2 +
Q_BB_D_DD_G_13_N_DD3 + Q_BB_D_DD_G_13_N_DD4 + Q_BB_D_DD_G_13_N_DD5 +
Q_BB_D_DD_G_13_N_DD6 + Q_BB_D_DD_G_14_N_DD1 + Q_BB_D_DD_G_14_N_DD2 +
Q_BB_D_DD_G_14_N_DD3 + Q_BB_D_DD_G_14_N_DD4 + Q_BB_D_DD_G_14_N_DD5 +
Q_BB_D_DD_G_14_N_DD6 + Q_BB_D_DD_G_15_N_DD1 + Q_BB_D_DD_G_15_N_DD2 +
Q_BB_D_DD_G_15_N_DD3 + Q_BB_D_DD_G_15_N_DD4 + Q_BB_D_DD_G_15_N_DD5 +
Q_BB_D_DD_G_15_N_DD6 - SGF_N = 0 ;
[_388] Q_BB_D_HH_G_1_S + Q_BB_D_HH_G_2_S + Q_BB_D_HH_G_3_S +
Q_BB_D_HH_G_4_S + Q_BB_D_HH_G_5_S + Q_BB_D_HH_G_6_S + Q_BB_D_HH_G_7_S +
Q_BB_D_HH_G_8_S + Q_BB_D_HH_G_9_S + Q_BB_D_HH_G_10_S + Q_BB_D_HH_G_11_S
+ Q_BB_D_HH_G_12_S + Q_BB_D_HH_G_13_S + Q_BB_D_HH_G_14_S +
Q_BB_D_HH_G_15_S + Q_BB_D_DD_G_1_S_DD1 + Q_BB_D_DD_G_1_S_DD2 +
Q_BB_D_DD_G_1_S_DD3 + Q_BB_D_DD_G_1_S_DD4 + Q_BB_D_DD_G_1_S_DD5 +
Q_BB_D_DD_G_1_S_DD6 + Q_BB_D_DD_G_2_S_DD1 + Q_BB_D_DD_G_2_S_DD2 +
Q_BB_D_DD_G_2_S_DD3 + Q_BB_D_DD_G_2_S_DD4 + Q_BB_D_DD_G_2_S_DD5 +
Q_BB_D_DD_G_2_S_DD6 + Q_BB_D_DD_G_3_S_DD1 + Q_BB_D_DD_G_3_S_DD2 +
Q_BB_D_DD_G_3_S_DD3 + Q_BB_D_DD_G_3_S_DD4 + Q_BB_D_DD_G_3_S_DD5 +
Q_BB_D_DD_G_3_S_DD6 + Q_BB_D_DD_G_4_S_DD1 + Q_BB_D_DD_G_4_S_DD2 +
Q_BB_D_DD_G_4_S_DD3 + Q_BB_D_DD_G_4_S_DD4 + Q_BB_D_DD_G_4_S_DD5 +
Q_BB_D_DD_G_4_S_DD6 + Q_BB_D_DD_G_5_S_DD1 + Q_BB_D_DD_G_5_S_DD2 +
Q_BB_D_DD_G_5_S_DD3 + Q_BB_D_DD_G_5_S_DD4 + Q_BB_D_DD_G_5_S_DD5 +
Q_BB_D_DD_G_5_S_DD6 + Q_BB_D_DD_G_6_S_DD1 + Q_BB_D_DD_G_6_S_DD2 +
Q_BB_D_DD_G_6_S_DD3 + Q_BB_D_DD_G_6_S_DD4 + Q_BB_D_DD_G_6_S_DD5 +
Q_BB_D_DD_G_6_S_DD6 + Q_BB_D_DD_G_7_S_DD1 + Q_BB_D_DD_G_7_S_DD2 +
Q_BB_D_DD_G_7_S_DD3 + Q_BB_D_DD_G_7_S_DD4 + Q_BB_D_DD_G_7_S_DD5 +
Q_BB_D_DD_G_7_S_DD6 + Q_BB_D_DD_G_8_S_DD1 + Q_BB_D_DD_G_8_S_DD2 +
Q_BB_D_DD_G_8_S_DD3 + Q_BB_D_DD_G_8_S_DD4 + Q_BB_D_DD_G_8_S_DD5 +
Q_BB_D_DD_G_8_S_DD6 + Q_BB_D_DD_G_9_S_DD1 + Q_BB_D_DD_G_9_S_DD2 +
Q_BB_D_DD_G_9_S_DD3 + Q_BB_D_DD_G_9_S_DD4 + Q_BB_D_DD_G_9_S_DD5 +
Q_BB_D_DD_G_9_S_DD6 + Q_BB_D_DD_G_10_S_DD1 + Q_BB_D_DD_G_10_S_DD2 +
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Q_BB_D_DD_G_10_S_DD3 + Q_BB_D_DD_G_10_S_DD4 + Q_BB_D_DD_G_10_S_DD5 +
Q_BB_D_DD_G_10_S_DD6 + Q_BB_D_DD_G_11_S_DD1 + Q_BB_D_DD_G_11_S_DD2 +
Q_BB_D_DD_G_11_S_DD3 + Q_BB_D_DD_G_11_S_DD4 + Q_BB_D_DD_G_11_S_DD5 +
Q_BB_D_DD_G_11_S_DD6 + Q_BB_D_DD_G_12_S_DD1 + Q_BB_D_DD_G_12_S_DD2 +
Q_BB_D_DD_G_12_S_DD3 + Q_BB_D_DD_G_12_S_DD4 + Q_BB_D_DD_G_12_S_DD5 +
Q_BB_D_DD_G_12_S_DD6 + Q_BB_D_DD_G_13_S_DD1 + Q_BB_D_DD_G_13_S_DD2 +
Q_BB_D_DD_G_13_S_DD3 + Q_BB_D_DD_G_13_S_DD4 + Q_BB_D_DD_G_13_S_DD5 +
Q_BB_D_DD_G_13_S_DD6 + Q_BB_D_DD_G_14_S_DD1 + Q_BB_D_DD_G_14_S_DD2 +
Q_BB_D_DD_G_14_S_DD3 + Q_BB_D_DD_G_14_S_DD4 + Q_BB_D_DD_G_14_S_DD5 +
Q_BB_D_DD_G_14_S_DD6 + Q_BB_D_DD_G_15_S_DD1 + Q_BB_D_DD_G_15_S_DD2 +
Q_BB_D_DD_G_15_S_DD3 + Q_BB_D_DD_G_15_S_DD4 + Q_BB_D_DD_G_15_S_DD5 +
Q_BB_D_DD_G_15_S_DD6 - SGF_S = 0 ;
[_389] SGF_E - SR_E - SDD_E - SIF_E - SCF_E = 0 ;
[_390] SGF_N - SR_N - SDD_N - SIF_N - SCF_N = 0 ;
[_391] SGF_S - SR_S - SDD_S - SIF_S - SCF_S = 0 ;
[_392] - 0.0421 * SGF_E + SR_E <= 0 ;
[_393] - 0.0421 * SGF_N + SR_N <= 0 ;
[_394] - 0.0421 * SGF_S + SR_S <= 0 ;
[_395] - 0.1053 * SGF_E + SDD_E <= 0 ;
[_396] - 0.1053 * SGF_N + SDD_N <= 0 ;
[_397] - 0.1053 * SGF_S + SDD_S <= 0 ;
[_398] - 0.1684 * SGF_E + SIF_E <= 0 ;
[_399] - 0.1684 * SGF_N + SIF_N <= 0 ;
[_400] - 0.1684 * SGF_S + SIF_S <= 0 ;
[_401] - 0.6842 * SGF_E + SCF_E <= 0 ;
[_402] - 0.6842 * SGF_N + SCF_N <= 0 ;
[_403] - 0.6842 * SGF_S + SCF_S <= 0 ;
[_404] - 0.03125 * SIF_E + IR_E = 0 ;
[_405] - 0.03125 * SIF_N + IR_N = 0 ;
[_406] - 0.03125 * SIF_S + IR_S = 0 ;
[_407] - 0.0625 * SIF_E + IIR_E = 0 ;
[_408] - 0.0625 * SIF_N + IIR_N = 0 ;
[_409] - 0.0625 * SIF_S + IIR_S = 0 ;
[_410] - 0.0919 * SIF_E + IAR_E = 0 ;
[_411] - 0.0919 * SIF_N + IAR_N = 0 ;
[_412] - 0.0919 * SIF_S + IAR_S = 0 ;
[_413] - 170 * SIF_E + IP_E = 0 ;
[_414] - 170 * SIF_N + IP_N = 0 ;
[_415] - 170 * SIF_S + IP_S = 0 ;
[_416] - 0.0192 * SCF_E + CR_E = 0 ;
[_417] - 0.0192 * SCF_N + CR_N = 0 ;
[_418] - 0.0192 * SCF_S + CR_S = 0 ;
[_419] - 0.0615 * SCF_E + CIR_E = 0 ;
[_420] - 0.0615 * SCF_N + CIR_N = 0 ;
[_421] - 0.0615 * SCF_S + CIR_S = 0 ;
[_422] - 0.1414 * SCF_E + CPR_E = 0 ;
[_423] - 0.1414 * SCF_N + CPR_N = 0 ;
[_424] - 0.1414 * SCF_S + CPR_S = 0 ;
[_425] - 0.2657 * SCF_E + CPD_E = 0 ;
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[_426] - 0.2657 * SCF_N + CPD_N = 0 ;
[_427] - 0.2657 * SCF_S + CPD_S = 0 ;
[_428] XF_E - XSILT_E - XFG_E - XFRJ_E = 0 ;
[_429] XF_N - XSILT_N - XFG_N - XFRJ_N = 0 ;
[_430] XF_S - XSILT_S - XFG_S - XFRJ_S = 0 ;
[_431] Q_BB_D_HH_S_1_E + Q_BB_D_HH_S_2_E + Q_BB_D_HH_S_3_E +
Q_BB_D_HH_S_4_E + Q_BB_D_HH_S_5_E + Q_BB_D_HH_S_6_E + Q_BB_D_HH_S_7_E +
Q_BB_D_HH_S_8_E + Q_BB_D_HH_S_9_E + Q_BB_D_HH_S_10_E + Q_BB_D_HH_S_11_E
+ Q_BB_D_HH_S_12_E + Q_BB_D_HH_S_13_E + Q_BB_D_HH_S_14_E +
Q_BB_D_HH_S_15_E - XSILT_E = 0 ;
[_432] Q_BB_D_HH_S_1_N + Q_BB_D_HH_S_2_N + Q_BB_D_HH_S_3_N +
Q_BB_D_HH_S_4_N + Q_BB_D_HH_S_5_N + Q_BB_D_HH_S_6_N + Q_BB_D_HH_S_7_N +
Q_BB_D_HH_S_8_N + Q_BB_D_HH_S_9_N + Q_BB_D_HH_S_10_N + Q_BB_D_HH_S_11_N
+ Q_BB_D_HH_S_12_N + Q_BB_D_HH_S_13_N + Q_BB_D_HH_S_14_N +
Q_BB_D_HH_S_15_N - XSILT_N = 0 ;
[_433] Q_BB_D_HH_S_1_S + Q_BB_D_HH_S_2_S + Q_BB_D_HH_S_3_S +
Q_BB_D_HH_S_4_S + Q_BB_D_HH_S_5_S + Q_BB_D_HH_S_6_S + Q_BB_D_HH_S_7_S +
Q_BB_D_HH_S_8_S + Q_BB_D_HH_S_9_S + Q_BB_D_HH_S_10_S + Q_BB_D_HH_S_11_S
+ Q_BB_D_HH_S_12_S + Q_BB_D_HH_S_13_S + Q_BB_D_HH_S_14_S +
Q_BB_D_HH_S_15_S - XSILT_S = 0 ;
[_434] - SDD_E + XFG_E = 0 ;
[_435] - SDD_N + XFG_N = 0 ;
[_436] - SDD_S + XFG_S = 0 ;
[_437] - IIR_E - IAR_E - CIR_E - CPR_E + XFRJ_E = 0 ;
[_438] - IIR_N - IAR_N - CIR_N - CPR_N + XFRJ_N = 0 ;
[_439] - IIR_S - IAR_S - CIR_S - CPR_S + XFRJ_S = 0 ;
[_440] SGF_E <= 5000 ;
[_441] SGF_N <= 5000 ;
[_442] SGF_S <= 5000 ;
[_443] SGF_E >= 0 ;
[_444] SGF_N >= 0 ;
[_445] SGF_S >= 0 ;
[_446] SIF_E <= 5000 ;
[_447] SIF_N <= 5000 ;
[_448] SIF_S <= 5000 ;
[_449] SIF_E >= 0 ;
[_450] SIF_N >= 0 ;
[_451] SIF_S >= 0 ;
[_452] XF_E <= 5000 ;
[_453] XF_N <= 5000 ;
[_454] XF_S <= 5000 ;
[_455] SCF_E <= 5000 ;
[_456] SCF_N <= 5000 ;
[_457] SCF_S <= 5000 ;
[_458] SCF_E >= 0 ;
[_459] SCF_N >= 0 ;
[_460] SCF_S >= 0 ;
[_461] - CTCX + 197.5 * XF_E + 204.14 * XF_N + 193.58 * XF_S = 0 ;
[_462] CTCS - 100 * SGF_E - 50 * SR_E - 100 * SGF_N - 50 * SR_N - 100 *
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SGF_S - 50 * SR_S = 0 ;
[_463] - CTCI + 689 * SIF_E + 50 * IR_E + 689 * SIF_N + 50 * IR_N + 689
* SIF_S + 50 * IR_S = 0 ;
[_464] - CTCC + 269 * SCF_E + 50 * CR_E + 269 * SCF_N + 50 * CR_N + 269
* SCF_S + 50 * CR_S = 0 ;
[_465] - CTREVC + 2500 * CPD_E + 2500 * CPD_N + 2500 * CPD_S = 0 ;
[_466] - CTREVI + 4.09 * IP_E + 4.09 * IP_N + 4.09 * IP_S = 0 ;
[_467] - CTREVR + 367.8586 * SR_E + 50 * IR_E + 50 * CR_E + 367.8586 *
SR_N + 50 * IR_N + 50 * CR_N + 367.8586 * SR_S + 50 * IR_S + 50 * CR_S =
0 ;
[_468] CTRANSP - CTCHH - CTCTRUCKS - CTC_DD1 - CTC_DD2 - CTC_DD3 -
CTC_DD4 - CTC_DD5 - CTC_DD6 = 0 ;
[_469] CTCHH - CTCGHH - CTCSHH = 0 ;
[_470] - CTCGHH + 277 * Q_BB_D_HH_G_1_E + 390 * Q_BB_D_HH_G_1_N + 468 *
Q_BB_D_HH_G_1_S + 277 * Q_BB_D_HH_G_2_E + 390 * Q_BB_D_HH_G_2_N + 468 *
Q_BB_D_HH_G_2_S + 243 * Q_BB_D_HH_G_3_E + 390 * Q_BB_D_HH_G_3_N + 468 *
Q_BB_D_HH_G_3_S + 243 * Q_BB_D_HH_G_4_E + 390 * Q_BB_D_HH_G_4_N + 468 *
Q_BB_D_HH_G_4_S + 243 * Q_BB_D_HH_G_5_E + 390 * Q_BB_D_HH_G_5_N + 468 *
Q_BB_D_HH_G_5_S + 243 * Q_BB_D_HH_G_6_E + 390 * Q_BB_D_HH_G_6_N + 468 *
Q_BB_D_HH_G_6_S + 243 * Q_BB_D_HH_G_7_E + 390 * Q_BB_D_HH_G_7_N + 468 *
Q_BB_D_HH_G_7_S + 243 * Q_BB_D_HH_G_8_E + 468 * Q_BB_D_HH_G_8_N + 390 *
Q_BB_D_HH_G_8_S + 277 * Q_BB_D_HH_G_9_E + 468 * Q_BB_D_HH_G_9_N + 390 *
Q_BB_D_HH_G_9_S + 243 * Q_BB_D_HH_G_10_E + 468 * Q_BB_D_HH_G_10_N + 390
* Q_BB_D_HH_G_10_S + 277 * Q_BB_D_HH_G_11_E + 468 * Q_BB_D_HH_G_11_N +
390 * Q_BB_D_HH_G_11_S + 243 * Q_BB_D_HH_G_12_E + 468 * Q_BB_D_HH_G_12_N
+ 390 * Q_BB_D_HH_G_12_S + 277 * Q_BB_D_HH_G_13_E + 468 *
Q_BB_D_HH_G_13_N + 390 * Q_BB_D_HH_G_13_S + 277 * Q_BB_D_HH_G_14_E + 468
* Q_BB_D_HH_G_14_N + 390 * Q_BB_D_HH_G_14_S + 277 * Q_BB_D_HH_G_15_E +
468 * Q_BB_D_HH_G_15_N + 468 * Q_BB_D_HH_G_15_S = 0 ;
[_471] - CTCSHH + 260 * Q_BB_D_HH_S_1_E + 360 * Q_BB_D_HH_S_1_N + 434 *
Q_BB_D_HH_S_1_S + 260 * Q_BB_D_HH_S_2_E + 360 * Q_BB_D_HH_S_2_N + 434 *
Q_BB_D_HH_S_2_S + 225 * Q_BB_D_HH_S_3_E + 360 * Q_BB_D_HH_S_3_N + 434 *
Q_BB_D_HH_S_3_S + 225 * Q_BB_D_HH_S_4_E + 360 * Q_BB_D_HH_S_4_N + 434 *
Q_BB_D_HH_S_4_S + 225 * Q_BB_D_HH_S_5_E + 360 * Q_BB_D_HH_S_5_N + 434 *
Q_BB_D_HH_S_5_S + 225 * Q_BB_D_HH_S_6_E + 360 * Q_BB_D_HH_S_6_N + 434 *
Q_BB_D_HH_S_6_S + 225 * Q_BB_D_HH_S_7_E + 360 * Q_BB_D_HH_S_7_N + 434 *
Q_BB_D_HH_S_7_S + 225 * Q_BB_D_HH_S_8_E + 434 * Q_BB_D_HH_S_8_N + 360 *
Q_BB_D_HH_S_8_S + 260 * Q_BB_D_HH_S_9_E + 434 * Q_BB_D_HH_S_9_N + 360 *
Q_BB_D_HH_S_9_S + 225 * Q_BB_D_HH_S_10_E + 434 * Q_BB_D_HH_S_10_N + 360
* Q_BB_D_HH_S_10_S + 260 * Q_BB_D_HH_S_11_E + 434 * Q_BB_D_HH_S_11_N +
360 * Q_BB_D_HH_S_11_S + 225 * Q_BB_D_HH_S_12_E + 434 * Q_BB_D_HH_S_12_N
+ 360 * Q_BB_D_HH_S_12_S + 260 * Q_BB_D_HH_S_13_E + 434 *
Q_BB_D_HH_S_13_N + 360 * Q_BB_D_HH_S_13_S + 260 * Q_BB_D_HH_S_14_E + 434
* Q_BB_D_HH_S_14_N + 360 * Q_BB_D_HH_S_14_S + 260 * Q_BB_D_HH_S_15_E +
434 * Q_BB_D_HH_S_15_N + 434 * Q_BB_D_HH_S_15_S = 0 ;
[_472] CTC_DD1 - CFUEL_DD1 = 71197.29000000001 ;
[_473] CTC_DD2 - CFUEL_DD2 = 331473.94 ;
[_474] CTC_DD3 - CFUEL_DD3 = 183642.24 ;
[_475] CTC_DD4 - CFUEL_DD4 = 521932.5600000001 ;
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[_476] CTC_DD5 - CFUEL_DD5 = 380110.7 ;
[_477] CTC_DD6 - CFUEL_DD6 = 21180.4 ;
[_478] - Q_BB_D_DD1_G_1_E + Q_BB_D_DD_G_1_E_DD1 = 0 ;
[_479] - Q_BB_D_DD1_G_1_N + Q_BB_D_DD_G_1_N_DD1 = 0 ;
[_480] - Q_BB_D_DD1_G_1_S + Q_BB_D_DD_G_1_S_DD1 = 0 ;
[_481] - Q_BB_D_DD1_G_2_E + Q_BB_D_DD_G_2_E_DD1 = 0 ;
[_482] - Q_BB_D_DD1_G_2_N + Q_BB_D_DD_G_2_N_DD1 = 0 ;
[_483] - Q_BB_D_DD1_G_2_S + Q_BB_D_DD_G_2_S_DD1 = 0 ;
[_484] - Q_BB_D_DD1_G_3_E + Q_BB_D_DD_G_3_E_DD1 = 0 ;
[_485] - Q_BB_D_DD1_G_3_N + Q_BB_D_DD_G_3_N_DD1 = 0 ;
[_486] - Q_BB_D_DD1_G_3_S + Q_BB_D_DD_G_3_S_DD1 = 0 ;
[_487] - Q_BB_D_DD1_G_4_E + Q_BB_D_DD_G_4_E_DD1 = 0 ;
[_488] - Q_BB_D_DD1_G_4_N + Q_BB_D_DD_G_4_N_DD1 = 0 ;
[_489] - Q_BB_D_DD1_G_4_S + Q_BB_D_DD_G_4_S_DD1 = 0 ;
[_490] - Q_BB_D_DD1_G_5_E + Q_BB_D_DD_G_5_E_DD1 = 0 ;
[_491] - Q_BB_D_DD1_G_5_N + Q_BB_D_DD_G_5_N_DD1 = 0 ;
[_492] - Q_BB_D_DD1_G_5_S + Q_BB_D_DD_G_5_S_DD1 = 0 ;
[_493] - Q_BB_D_DD1_G_6_E + Q_BB_D_DD_G_6_E_DD1 = 0 ;
[_494] - Q_BB_D_DD1_G_6_N + Q_BB_D_DD_G_6_N_DD1 = 0 ;
[_495] - Q_BB_D_DD1_G_6_S + Q_BB_D_DD_G_6_S_DD1 = 0 ;
[_496] - Q_BB_D_DD1_G_7_E + Q_BB_D_DD_G_7_E_DD1 = 0 ;
[_497] - Q_BB_D_DD1_G_7_N + Q_BB_D_DD_G_7_N_DD1 = 0 ;
[_498] - Q_BB_D_DD1_G_7_S + Q_BB_D_DD_G_7_S_DD1 = 0 ;
[_499] - Q_BB_D_DD1_G_8_E + Q_BB_D_DD_G_8_E_DD1 = 0 ;
[_500] - Q_BB_D_DD1_G_8_N + Q_BB_D_DD_G_8_N_DD1 = 0 ;
[_501] - Q_BB_D_DD1_G_8_S + Q_BB_D_DD_G_8_S_DD1 = 0 ;
[_502] - Q_BB_D_DD1_G_9_E + Q_BB_D_DD_G_9_E_DD1 = 0 ;
[_503] - Q_BB_D_DD1_G_9_N + Q_BB_D_DD_G_9_N_DD1 = 0 ;
[_504] - Q_BB_D_DD1_G_9_S + Q_BB_D_DD_G_9_S_DD1 = 0 ;
[_505] - Q_BB_D_DD1_G_10_E + Q_BB_D_DD_G_10_E_DD1 = 0 ;
[_506] - Q_BB_D_DD1_G_10_N + Q_BB_D_DD_G_10_N_DD1 = 0 ;
[_507] - Q_BB_D_DD1_G_10_S + Q_BB_D_DD_G_10_S_DD1 = 0 ;
[_508] - Q_BB_D_DD1_G_11_E + Q_BB_D_DD_G_11_E_DD1 = 0 ;
[_509] - Q_BB_D_DD1_G_11_N + Q_BB_D_DD_G_11_N_DD1 = 0 ;
[_510] - Q_BB_D_DD1_G_11_S + Q_BB_D_DD_G_11_S_DD1 = 0 ;
[_511] - Q_BB_D_DD1_G_12_E + Q_BB_D_DD_G_12_E_DD1 = 0 ;
[_512] - Q_BB_D_DD1_G_12_N + Q_BB_D_DD_G_12_N_DD1 = 0 ;
[_513] - Q_BB_D_DD1_G_12_S + Q_BB_D_DD_G_12_S_DD1 = 0 ;
[_514] - Q_BB_D_DD1_G_13_E + Q_BB_D_DD_G_13_E_DD1 = 0 ;
[_515] - Q_BB_D_DD1_G_13_N + Q_BB_D_DD_G_13_N_DD1 = 0 ;
[_516] - Q_BB_D_DD1_G_13_S + Q_BB_D_DD_G_13_S_DD1 = 0 ;
[_517] - Q_BB_D_DD1_G_14_E + Q_BB_D_DD_G_14_E_DD1 = 0 ;
[_518] - Q_BB_D_DD1_G_14_N + Q_BB_D_DD_G_14_N_DD1 = 0 ;
[_519] - Q_BB_D_DD1_G_14_S + Q_BB_D_DD_G_14_S_DD1 = 0 ;
[_520] - Q_BB_D_DD1_G_15_E + Q_BB_D_DD_G_15_E_DD1 = 0 ;
[_521] - Q_BB_D_DD1_G_15_N + Q_BB_D_DD_G_15_N_DD1 = 0 ;
[_522] - Q_BB_D_DD1_G_15_S + Q_BB_D_DD_G_15_S_DD1 = 0 ;
[_523] - Q_BB_D_DD2_G_1_E + Q_BB_D_DD_G_1_E_DD2 = 0 ;
[_524] - Q_BB_D_DD2_G_1_N + Q_BB_D_DD_G_1_N_DD2 = 0 ;
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[_525] - Q_BB_D_DD2_G_1_S + Q_BB_D_DD_G_1_S_DD2 = 0 ;
[_526] - Q_BB_D_DD2_G_2_E + Q_BB_D_DD_G_2_E_DD2 = 0 ;
[_527] - Q_BB_D_DD2_G_2_N + Q_BB_D_DD_G_2_N_DD2 = 0 ;
[_528] - Q_BB_D_DD2_G_2_S + Q_BB_D_DD_G_2_S_DD2 = 0 ;
[_529] - Q_BB_D_DD2_G_3_E + Q_BB_D_DD_G_3_E_DD2 = 0 ;
[_530] - Q_BB_D_DD2_G_3_N + Q_BB_D_DD_G_3_N_DD2 = 0 ;
[_531] - Q_BB_D_DD2_G_3_S + Q_BB_D_DD_G_3_S_DD2 = 0 ;
[_532] - Q_BB_D_DD2_G_4_E + Q_BB_D_DD_G_4_E_DD2 = 0 ;
[_533] - Q_BB_D_DD2_G_4_N + Q_BB_D_DD_G_4_N_DD2 = 0 ;
[_534] - Q_BB_D_DD2_G_4_S + Q_BB_D_DD_G_4_S_DD2 = 0 ;
[_535] - Q_BB_D_DD2_G_5_E + Q_BB_D_DD_G_5_E_DD2 = 0 ;
[_536] - Q_BB_D_DD2_G_5_N + Q_BB_D_DD_G_5_N_DD2 = 0 ;
[_537] - Q_BB_D_DD2_G_5_S + Q_BB_D_DD_G_5_S_DD2 = 0 ;
[_538] - Q_BB_D_DD2_G_6_E + Q_BB_D_DD_G_6_E_DD2 = 0 ;
[_539] - Q_BB_D_DD2_G_6_N + Q_BB_D_DD_G_6_N_DD2 = 0 ;
[_540] - Q_BB_D_DD2_G_6_S + Q_BB_D_DD_G_6_S_DD2 = 0 ;
[_541] - Q_BB_D_DD2_G_7_E + Q_BB_D_DD_G_7_E_DD2 = 0 ;
[_542] - Q_BB_D_DD2_G_7_N + Q_BB_D_DD_G_7_N_DD2 = 0 ;
[_543] - Q_BB_D_DD2_G_7_S + Q_BB_D_DD_G_7_S_DD2 = 0 ;
[_544] - Q_BB_D_DD2_G_8_E + Q_BB_D_DD_G_8_E_DD2 = 0 ;
[_545] - Q_BB_D_DD2_G_8_N + Q_BB_D_DD_G_8_N_DD2 = 0 ;
[_546] - Q_BB_D_DD2_G_8_S + Q_BB_D_DD_G_8_S_DD2 = 0 ;
[_547] - Q_BB_D_DD2_G_9_E + Q_BB_D_DD_G_9_E_DD2 = 0 ;
[_548] - Q_BB_D_DD2_G_9_N + Q_BB_D_DD_G_9_N_DD2 = 0 ;
[_549] - Q_BB_D_DD2_G_9_S + Q_BB_D_DD_G_9_S_DD2 = 0 ;
[_550] - Q_BB_D_DD2_G_10_E + Q_BB_D_DD_G_10_E_DD2 = 0 ;
[_551] - Q_BB_D_DD2_G_10_N + Q_BB_D_DD_G_10_N_DD2 = 0 ;
[_552] - Q_BB_D_DD2_G_10_S + Q_BB_D_DD_G_10_S_DD2 = 0 ;
[_553] - Q_BB_D_DD2_G_11_E + Q_BB_D_DD_G_11_E_DD2 = 0 ;
[_554] - Q_BB_D_DD2_G_11_N + Q_BB_D_DD_G_11_N_DD2 = 0 ;
[_555] - Q_BB_D_DD2_G_11_S + Q_BB_D_DD_G_11_S_DD2 = 0 ;
[_556] - Q_BB_D_DD2_G_12_E + Q_BB_D_DD_G_12_E_DD2 = 0 ;
[_557] - Q_BB_D_DD2_G_12_N + Q_BB_D_DD_G_12_N_DD2 = 0 ;
[_558] - Q_BB_D_DD2_G_12_S + Q_BB_D_DD_G_12_S_DD2 = 0 ;
[_559] - Q_BB_D_DD2_G_13_E + Q_BB_D_DD_G_13_E_DD2 = 0 ;
[_560] - Q_BB_D_DD2_G_13_N + Q_BB_D_DD_G_13_N_DD2 = 0 ;
[_561] - Q_BB_D_DD2_G_13_S + Q_BB_D_DD_G_13_S_DD2 = 0 ;
[_562] - Q_BB_D_DD2_G_14_E + Q_BB_D_DD_G_14_E_DD2 = 0 ;
[_563] - Q_BB_D_DD2_G_14_N + Q_BB_D_DD_G_14_N_DD2 = 0 ;
[_564] - Q_BB_D_DD2_G_14_S + Q_BB_D_DD_G_14_S_DD2 = 0 ;
[_565] - Q_BB_D_DD2_G_15_E + Q_BB_D_DD_G_15_E_DD2 = 0 ;
[_566] - Q_BB_D_DD2_G_15_N + Q_BB_D_DD_G_15_N_DD2 = 0 ;
[_567] - Q_BB_D_DD2_G_15_S + Q_BB_D_DD_G_15_S_DD2 = 0 ;
[_568] - Q_BB_D_DD3_G_1_E + Q_BB_D_DD_G_1_E_DD3 = 0 ;
[_569] - Q_BB_D_DD3_G_1_N + Q_BB_D_DD_G_1_N_DD3 = 0 ;
[_570] - Q_BB_D_DD3_G_1_S + Q_BB_D_DD_G_1_S_DD3 = 0 ;
[_571] - Q_BB_D_DD3_G_2_E + Q_BB_D_DD_G_2_E_DD3 = 0 ;
[_572] - Q_BB_D_DD3_G_2_N + Q_BB_D_DD_G_2_N_DD3 = 0 ;
[_573] - Q_BB_D_DD3_G_2_S + Q_BB_D_DD_G_2_S_DD3 = 0 ;
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[_574] - Q_BB_D_DD3_G_3_E + Q_BB_D_DD_G_3_E_DD3 = 0 ;
[_575] - Q_BB_D_DD3_G_3_N + Q_BB_D_DD_G_3_N_DD3 = 0 ;
[_576] - Q_BB_D_DD3_G_3_S + Q_BB_D_DD_G_3_S_DD3 = 0 ;
[_577] - Q_BB_D_DD3_G_4_E + Q_BB_D_DD_G_4_E_DD3 = 0 ;
[_578] - Q_BB_D_DD3_G_4_N + Q_BB_D_DD_G_4_N_DD3 = 0 ;
[_579] - Q_BB_D_DD3_G_4_S + Q_BB_D_DD_G_4_S_DD3 = 0 ;
[_580] - Q_BB_D_DD3_G_5_E + Q_BB_D_DD_G_5_E_DD3 = 0 ;
[_581] - Q_BB_D_DD3_G_5_N + Q_BB_D_DD_G_5_N_DD3 = 0 ;
[_582] - Q_BB_D_DD3_G_5_S + Q_BB_D_DD_G_5_S_DD3 = 0 ;
[_583] - Q_BB_D_DD3_G_6_E + Q_BB_D_DD_G_6_E_DD3 = 0 ;
[_584] - Q_BB_D_DD3_G_6_N + Q_BB_D_DD_G_6_N_DD3 = 0 ;
[_585] - Q_BB_D_DD3_G_6_S + Q_BB_D_DD_G_6_S_DD3 = 0 ;
[_586] - Q_BB_D_DD3_G_7_E + Q_BB_D_DD_G_7_E_DD3 = 0 ;
[_587] - Q_BB_D_DD3_G_7_N + Q_BB_D_DD_G_7_N_DD3 = 0 ;
[_588] - Q_BB_D_DD3_G_7_S + Q_BB_D_DD_G_7_S_DD3 = 0 ;
[_589] - Q_BB_D_DD3_G_8_E + Q_BB_D_DD_G_8_E_DD3 = 0 ;
[_590] - Q_BB_D_DD3_G_8_N + Q_BB_D_DD_G_8_N_DD3 = 0 ;
[_591] - Q_BB_D_DD3_G_8_S + Q_BB_D_DD_G_8_S_DD3 = 0 ;
[_592] - Q_BB_D_DD3_G_9_E + Q_BB_D_DD_G_9_E_DD3 = 0 ;
[_593] - Q_BB_D_DD3_G_9_N + Q_BB_D_DD_G_9_N_DD3 = 0 ;
[_594] - Q_BB_D_DD3_G_9_S + Q_BB_D_DD_G_9_S_DD3 = 0 ;
[_595] - Q_BB_D_DD3_G_10_E + Q_BB_D_DD_G_10_E_DD3 = 0 ;
[_596] - Q_BB_D_DD3_G_10_N + Q_BB_D_DD_G_10_N_DD3 = 0 ;
[_597] - Q_BB_D_DD3_G_10_S + Q_BB_D_DD_G_10_S_DD3 = 0 ;
[_598] - Q_BB_D_DD3_G_11_E + Q_BB_D_DD_G_11_E_DD3 = 0 ;
[_599] - Q_BB_D_DD3_G_11_N + Q_BB_D_DD_G_11_N_DD3 = 0 ;
[_600] - Q_BB_D_DD3_G_11_S + Q_BB_D_DD_G_11_S_DD3 = 0 ;
[_601] - Q_BB_D_DD3_G_12_E + Q_BB_D_DD_G_12_E_DD3 = 0 ;
[_602] - Q_BB_D_DD3_G_12_N + Q_BB_D_DD_G_12_N_DD3 = 0 ;
[_603] - Q_BB_D_DD3_G_12_S + Q_BB_D_DD_G_12_S_DD3 = 0 ;
[_604] - Q_BB_D_DD3_G_13_E + Q_BB_D_DD_G_13_E_DD3 = 0 ;
[_605] - Q_BB_D_DD3_G_13_N + Q_BB_D_DD_G_13_N_DD3 = 0 ;
[_606] - Q_BB_D_DD3_G_13_S + Q_BB_D_DD_G_13_S_DD3 = 0 ;
[_607] - Q_BB_D_DD3_G_14_E + Q_BB_D_DD_G_14_E_DD3 = 0 ;
[_608] - Q_BB_D_DD3_G_14_N + Q_BB_D_DD_G_14_N_DD3 = 0 ;
[_609] - Q_BB_D_DD3_G_14_S + Q_BB_D_DD_G_14_S_DD3 = 0 ;
[_610] - Q_BB_D_DD3_G_15_E + Q_BB_D_DD_G_15_E_DD3 = 0 ;
[_611] - Q_BB_D_DD3_G_15_N + Q_BB_D_DD_G_15_N_DD3 = 0 ;
[_612] - Q_BB_D_DD3_G_15_S + Q_BB_D_DD_G_15_S_DD3 = 0 ;
[_613] - Q_BB_D_DD4_G_1_E + Q_BB_D_DD_G_1_E_DD4 = 0 ;
[_614] - Q_BB_D_DD4_G_1_N + Q_BB_D_DD_G_1_N_DD4 = 0 ;
[_615] - Q_BB_D_DD4_G_1_S + Q_BB_D_DD_G_1_S_DD4 = 0 ;
[_616] - Q_BB_D_DD4_G_2_E + Q_BB_D_DD_G_2_E_DD4 = 0 ;
[_617] - Q_BB_D_DD4_G_2_N + Q_BB_D_DD_G_2_N_DD4 = 0 ;
[_618] - Q_BB_D_DD4_G_2_S + Q_BB_D_DD_G_2_S_DD4 = 0 ;
[_619] - Q_BB_D_DD4_G_3_E + Q_BB_D_DD_G_3_E_DD4 = 0 ;
[_620] - Q_BB_D_DD4_G_3_N + Q_BB_D_DD_G_3_N_DD4 = 0 ;
[_621] - Q_BB_D_DD4_G_3_S + Q_BB_D_DD_G_3_S_DD4 = 0 ;
[_622] - Q_BB_D_DD4_G_4_E + Q_BB_D_DD_G_4_E_DD4 = 0 ;
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[_623] - Q_BB_D_DD4_G_4_N + Q_BB_D_DD_G_4_N_DD4 = 0 ;
[_624] - Q_BB_D_DD4_G_4_S + Q_BB_D_DD_G_4_S_DD4 = 0 ;
[_625] - Q_BB_D_DD4_G_5_E + Q_BB_D_DD_G_5_E_DD4 = 0 ;
[_626] - Q_BB_D_DD4_G_5_N + Q_BB_D_DD_G_5_N_DD4 = 0 ;
[_627] - Q_BB_D_DD4_G_5_S + Q_BB_D_DD_G_5_S_DD4 = 0 ;
[_628] - Q_BB_D_DD4_G_6_E + Q_BB_D_DD_G_6_E_DD4 = 0 ;
[_629] - Q_BB_D_DD4_G_6_N + Q_BB_D_DD_G_6_N_DD4 = 0 ;
[_630] - Q_BB_D_DD4_G_6_S + Q_BB_D_DD_G_6_S_DD4 = 0 ;
[_631] - Q_BB_D_DD4_G_7_E + Q_BB_D_DD_G_7_E_DD4 = 0 ;
[_632] - Q_BB_D_DD4_G_7_N + Q_BB_D_DD_G_7_N_DD4 = 0 ;
[_633] - Q_BB_D_DD4_G_7_S + Q_BB_D_DD_G_7_S_DD4 = 0 ;
[_634] - Q_BB_D_DD4_G_8_E + Q_BB_D_DD_G_8_E_DD4 = 0 ;
[_635] - Q_BB_D_DD4_G_8_N + Q_BB_D_DD_G_8_N_DD4 = 0 ;
[_636] - Q_BB_D_DD4_G_8_S + Q_BB_D_DD_G_8_S_DD4 = 0 ;
[_637] - Q_BB_D_DD4_G_9_E + Q_BB_D_DD_G_9_E_DD4 = 0 ;
[_638] - Q_BB_D_DD4_G_9_N + Q_BB_D_DD_G_9_N_DD4 = 0 ;
[_639] - Q_BB_D_DD4_G_9_S + Q_BB_D_DD_G_9_S_DD4 = 0 ;
[_640] - Q_BB_D_DD4_G_10_E + Q_BB_D_DD_G_10_E_DD4 = 0 ;
[_641] - Q_BB_D_DD4_G_10_N + Q_BB_D_DD_G_10_N_DD4 = 0 ;
[_642] - Q_BB_D_DD4_G_10_S + Q_BB_D_DD_G_10_S_DD4 = 0 ;
[_643] - Q_BB_D_DD4_G_11_E + Q_BB_D_DD_G_11_E_DD4 = 0 ;
[_644] - Q_BB_D_DD4_G_11_N + Q_BB_D_DD_G_11_N_DD4 = 0 ;
[_645] - Q_BB_D_DD4_G_11_S + Q_BB_D_DD_G_11_S_DD4 = 0 ;
[_646] - Q_BB_D_DD4_G_12_E + Q_BB_D_DD_G_12_E_DD4 = 0 ;
[_647] - Q_BB_D_DD4_G_12_N + Q_BB_D_DD_G_12_N_DD4 = 0 ;
[_648] - Q_BB_D_DD4_G_12_S + Q_BB_D_DD_G_12_S_DD4 = 0 ;
[_649] - Q_BB_D_DD4_G_13_E + Q_BB_D_DD_G_13_E_DD4 = 0 ;
[_650] - Q_BB_D_DD4_G_13_N + Q_BB_D_DD_G_13_N_DD4 = 0 ;
[_651] - Q_BB_D_DD4_G_13_S + Q_BB_D_DD_G_13_S_DD4 = 0 ;
[_652] - Q_BB_D_DD4_G_14_E + Q_BB_D_DD_G_14_E_DD4 = 0 ;
[_653] - Q_BB_D_DD4_G_14_N + Q_BB_D_DD_G_14_N_DD4 = 0 ;
[_654] - Q_BB_D_DD4_G_14_S + Q_BB_D_DD_G_14_S_DD4 = 0 ;
[_655] - Q_BB_D_DD4_G_15_E + Q_BB_D_DD_G_15_E_DD4 = 0 ;
[_656] - Q_BB_D_DD4_G_15_N + Q_BB_D_DD_G_15_N_DD4 = 0 ;
[_657] - Q_BB_D_DD4_G_15_S + Q_BB_D_DD_G_15_S_DD4 = 0 ;
[_658] - Q_BB_D_DD5_G_1_E + Q_BB_D_DD_G_1_E_DD5 = 0 ;
[_659] - Q_BB_D_DD5_G_1_N + Q_BB_D_DD_G_1_N_DD5 = 0 ;
[_660] - Q_BB_D_DD5_G_1_S + Q_BB_D_DD_G_1_S_DD5 = 0 ;
[_661] - Q_BB_D_DD5_G_2_E + Q_BB_D_DD_G_2_E_DD5 = 0 ;
[_662] - Q_BB_D_DD5_G_2_N + Q_BB_D_DD_G_2_N_DD5 = 0 ;
[_663] - Q_BB_D_DD5_G_2_S + Q_BB_D_DD_G_2_S_DD5 = 0 ;
[_664] - Q_BB_D_DD5_G_3_E + Q_BB_D_DD_G_3_E_DD5 = 0 ;
[_665] - Q_BB_D_DD5_G_3_N + Q_BB_D_DD_G_3_N_DD5 = 0 ;
[_666] - Q_BB_D_DD5_G_3_S + Q_BB_D_DD_G_3_S_DD5 = 0 ;
[_667] - Q_BB_D_DD5_G_4_E + Q_BB_D_DD_G_4_E_DD5 = 0 ;
[_668] - Q_BB_D_DD5_G_4_N + Q_BB_D_DD_G_4_N_DD5 = 0 ;
[_669] - Q_BB_D_DD5_G_4_S + Q_BB_D_DD_G_4_S_DD5 = 0 ;
[_670] - Q_BB_D_DD5_G_5_E + Q_BB_D_DD_G_5_E_DD5 = 0 ;
[_671] - Q_BB_D_DD5_G_5_N + Q_BB_D_DD_G_5_N_DD5 = 0 ;
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[_672] - Q_BB_D_DD5_G_5_S + Q_BB_D_DD_G_5_S_DD5 = 0 ;
[_673] - Q_BB_D_DD5_G_6_E + Q_BB_D_DD_G_6_E_DD5 = 0 ;
[_674] - Q_BB_D_DD5_G_6_N + Q_BB_D_DD_G_6_N_DD5 = 0 ;
[_675] - Q_BB_D_DD5_G_6_S + Q_BB_D_DD_G_6_S_DD5 = 0 ;
[_676] - Q_BB_D_DD5_G_7_E + Q_BB_D_DD_G_7_E_DD5 = 0 ;
[_677] - Q_BB_D_DD5_G_7_N + Q_BB_D_DD_G_7_N_DD5 = 0 ;
[_678] - Q_BB_D_DD5_G_7_S + Q_BB_D_DD_G_7_S_DD5 = 0 ;
[_679] - Q_BB_D_DD5_G_8_E + Q_BB_D_DD_G_8_E_DD5 = 0 ;
[_680] - Q_BB_D_DD5_G_8_N + Q_BB_D_DD_G_8_N_DD5 = 0 ;
[_681] - Q_BB_D_DD5_G_8_S + Q_BB_D_DD_G_8_S_DD5 = 0 ;
[_682] - Q_BB_D_DD5_G_9_E + Q_BB_D_DD_G_9_E_DD5 = 0 ;
[_683] - Q_BB_D_DD5_G_9_N + Q_BB_D_DD_G_9_N_DD5 = 0 ;
[_684] - Q_BB_D_DD5_G_9_S + Q_BB_D_DD_G_9_S_DD5 = 0 ;
[_685] - Q_BB_D_DD5_G_10_E + Q_BB_D_DD_G_10_E_DD5 = 0 ;
[_686] - Q_BB_D_DD5_G_10_N + Q_BB_D_DD_G_10_N_DD5 = 0 ;
[_687] - Q_BB_D_DD5_G_10_S + Q_BB_D_DD_G_10_S_DD5 = 0 ;
[_688] - Q_BB_D_DD5_G_11_E + Q_BB_D_DD_G_11_E_DD5 = 0 ;
[_689] - Q_BB_D_DD5_G_11_N + Q_BB_D_DD_G_11_N_DD5 = 0 ;
[_690] - Q_BB_D_DD5_G_11_S + Q_BB_D_DD_G_11_S_DD5 = 0 ;
[_691] - Q_BB_D_DD5_G_12_E + Q_BB_D_DD_G_12_E_DD5 = 0 ;
[_692] - Q_BB_D_DD5_G_12_N + Q_BB_D_DD_G_12_N_DD5 = 0 ;
[_693] - Q_BB_D_DD5_G_12_S + Q_BB_D_DD_G_12_S_DD5 = 0 ;
[_694] - Q_BB_D_DD5_G_13_E + Q_BB_D_DD_G_13_E_DD5 = 0 ;
[_695] - Q_BB_D_DD5_G_13_N + Q_BB_D_DD_G_13_N_DD5 = 0 ;
[_696] - Q_BB_D_DD5_G_13_S + Q_BB_D_DD_G_13_S_DD5 = 0 ;
[_697] - Q_BB_D_DD5_G_14_E + Q_BB_D_DD_G_14_E_DD5 = 0 ;
[_698] - Q_BB_D_DD5_G_14_N + Q_BB_D_DD_G_14_N_DD5 = 0 ;
[_699] - Q_BB_D_DD5_G_14_S + Q_BB_D_DD_G_14_S_DD5 = 0 ;
[_700] - Q_BB_D_DD5_G_15_E + Q_BB_D_DD_G_15_E_DD5 = 0 ;
[_701] - Q_BB_D_DD5_G_15_N + Q_BB_D_DD_G_15_N_DD5 = 0 ;
[_702] - Q_BB_D_DD5_G_15_S + Q_BB_D_DD_G_15_S_DD5 = 0 ;
[_703] - Q_BB_D_DD6_G_1_E + Q_BB_D_DD_G_1_E_DD6 = 0 ;
[_704] - Q_BB_D_DD6_G_1_N + Q_BB_D_DD_G_1_N_DD6 = 0 ;
[_705] - Q_BB_D_DD6_G_1_S + Q_BB_D_DD_G_1_S_DD6 = 0 ;
[_706] - Q_BB_D_DD6_G_2_E + Q_BB_D_DD_G_2_E_DD6 = 0 ;
[_707] - Q_BB_D_DD6_G_2_N + Q_BB_D_DD_G_2_N_DD6 = 0 ;
[_708] - Q_BB_D_DD6_G_2_S + Q_BB_D_DD_G_2_S_DD6 = 0 ;
[_709] - Q_BB_D_DD6_G_3_E + Q_BB_D_DD_G_3_E_DD6 = 0 ;
[_710] - Q_BB_D_DD6_G_3_N + Q_BB_D_DD_G_3_N_DD6 = 0 ;
[_711] - Q_BB_D_DD6_G_3_S + Q_BB_D_DD_G_3_S_DD6 = 0 ;
[_712] - Q_BB_D_DD6_G_4_E + Q_BB_D_DD_G_4_E_DD6 = 0 ;
[_713] - Q_BB_D_DD6_G_4_N + Q_BB_D_DD_G_4_N_DD6 = 0 ;
[_714] - Q_BB_D_DD6_G_4_S + Q_BB_D_DD_G_4_S_DD6 = 0 ;
[_715] - Q_BB_D_DD6_G_5_E + Q_BB_D_DD_G_5_E_DD6 = 0 ;
[_716] - Q_BB_D_DD6_G_5_N + Q_BB_D_DD_G_5_N_DD6 = 0 ;
[_717] - Q_BB_D_DD6_G_5_S + Q_BB_D_DD_G_5_S_DD6 = 0 ;
[_718] - Q_BB_D_DD6_G_6_E + Q_BB_D_DD_G_6_E_DD6 = 0 ;
[_719] - Q_BB_D_DD6_G_6_N + Q_BB_D_DD_G_6_N_DD6 = 0 ;
[_720] - Q_BB_D_DD6_G_6_S + Q_BB_D_DD_G_6_S_DD6 = 0 ;
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[_721] - Q_BB_D_DD6_G_7_E + Q_BB_D_DD_G_7_E_DD6 = 0 ;
[_722] - Q_BB_D_DD6_G_7_N + Q_BB_D_DD_G_7_N_DD6 = 0 ;
[_723] - Q_BB_D_DD6_G_7_S + Q_BB_D_DD_G_7_S_DD6 = 0 ;
[_724] - Q_BB_D_DD6_G_8_E + Q_BB_D_DD_G_8_E_DD6 = 0 ;
[_725] - Q_BB_D_DD6_G_8_N + Q_BB_D_DD_G_8_N_DD6 = 0 ;
[_726] - Q_BB_D_DD6_G_8_S + Q_BB_D_DD_G_8_S_DD6 = 0 ;
[_727] - Q_BB_D_DD6_G_9_E + Q_BB_D_DD_G_9_E_DD6 = 0 ;
[_728] - Q_BB_D_DD6_G_9_N + Q_BB_D_DD_G_9_N_DD6 = 0 ;
[_729] - Q_BB_D_DD6_G_9_S + Q_BB_D_DD_G_9_S_DD6 = 0 ;
[_730] - Q_BB_D_DD6_G_10_E + Q_BB_D_DD_G_10_E_DD6 = 0 ;
[_731] - Q_BB_D_DD6_G_10_N + Q_BB_D_DD_G_10_N_DD6 = 0 ;
[_732] - Q_BB_D_DD6_G_10_S + Q_BB_D_DD_G_10_S_DD6 = 0 ;
[_733] - Q_BB_D_DD6_G_11_E + Q_BB_D_DD_G_11_E_DD6 = 0 ;
[_734] - Q_BB_D_DD6_G_11_N + Q_BB_D_DD_G_11_N_DD6 = 0 ;
[_735] - Q_BB_D_DD6_G_11_S + Q_BB_D_DD_G_11_S_DD6 = 0 ;
[_736] - Q_BB_D_DD6_G_12_E + Q_BB_D_DD_G_12_E_DD6 = 0 ;
[_737] - Q_BB_D_DD6_G_12_N + Q_BB_D_DD_G_12_N_DD6 = 0 ;
[_738] - Q_BB_D_DD6_G_12_S + Q_BB_D_DD_G_12_S_DD6 = 0 ;
[_739] - Q_BB_D_DD6_G_13_E + Q_BB_D_DD_G_13_E_DD6 = 0 ;
[_740] - Q_BB_D_DD6_G_13_N + Q_BB_D_DD_G_13_N_DD6 = 0 ;
[_741] - Q_BB_D_DD6_G_13_S + Q_BB_D_DD_G_13_S_DD6 = 0 ;
[_742] - Q_BB_D_DD6_G_14_E + Q_BB_D_DD_G_14_E_DD6 = 0 ;
[_743] - Q_BB_D_DD6_G_14_N + Q_BB_D_DD_G_14_N_DD6 = 0 ;
[_744] - Q_BB_D_DD6_G_14_S + Q_BB_D_DD_G_14_S_DD6 = 0 ;
[_745] - Q_BB_D_DD6_G_15_E + Q_BB_D_DD_G_15_E_DD6 = 0 ;
[_746] - Q_BB_D_DD6_G_15_N + Q_BB_D_DD_G_15_N_DD6 = 0 ;
[_747] - Q_BB_D_DD6_G_15_S + Q_BB_D_DD_G_15_S_DD6 = 0 ;
[_748] 147.89 * Q_BB_D_DD1_G_1_E + 28.98 * Q_BB_D_DD1_G_1_N + 249.05 *
Q_BB_D_DD1_G_1_S + 118.36 * Q_BB_D_DD1_G_2_E + 60.94 * Q_BB_D_DD1_G_2_N
+ 214.65 * Q_BB_D_DD1_G_2_S + 95.2 * Q_BB_D_DD1_G_3_E +
96.29000000000001 * Q_BB_D_DD1_G_3_N + 227.11 * Q_BB_D_DD1_G_3_S +
103.87 * Q_BB_D_DD1_G_4_E + 81.66 * Q_BB_D_DD1_G_4_N + 196.24 *
Q_BB_D_DD1_G_4_S + 87.34999999999999 * Q_BB_D_DD1_G_5_E +
99.40000000000001 * Q_BB_D_DD1_G_5_N + 178.36 * Q_BB_D_DD1_G_5_S + 80.45
* Q_BB_D_DD1_G_6_E + 122.97 * Q_BB_D_DD1_G_6_N + 167.12 *
Q_BB_D_DD1_G_6_S + 22.34 * Q_BB_D_DD1_G_7_E + 153.3 * Q_BB_D_DD1_G_7_N +
166.71 * Q_BB_D_DD1_G_7_S + 70.34999999999999 * Q_BB_D_DD1_G_8_E + 174.7
* Q_BB_D_DD1_G_8_N + 108.75 * Q_BB_D_DD1_G_8_S + 122.43 *
Q_BB_D_DD1_G_9_E + 194.2 * Q_BB_D_DD1_G_9_N + 121.8 * Q_BB_D_DD1_G_9_S +
109.29 * Q_BB_D_DD1_G_10_E + 227.11 * Q_BB_D_DD1_G_10_N + 83.49 *
Q_BB_D_DD1_G_10_S + 138.68 * Q_BB_D_DD1_G_11_E + 263.68 *
Q_BB_D_DD1_G_11_N + 64.95 * Q_BB_D_DD1_G_11_S + 54.58 *
Q_BB_D_DD1_G_12_E + 226.03 * Q_BB_D_DD1_G_12_N + 151.54 *
Q_BB_D_DD1_G_12_S + 156.01 * Q_BB_D_DD1_G_13_E + 258.26 *
Q_BB_D_DD1_G_13_N + 47.94 * Q_BB_D_DD1_G_13_S + 186.96 *
Q_BB_D_DD1_G_14_E + 269.23 * Q_BB_D_DD1_G_14_N + 92.77 *
Q_BB_D_DD1_G_14_S + 216.42 * Q_BB_D_DD1_G_15_E + 274.24 *
Q_BB_D_DD1_G_15_N + 220.75 * Q_BB_D_DD1_G_15_S - CFUEL_DD1 = 0 ;
[_749] 157.63 * Q_BB_D_DD2_G_1_E + 30.89 * Q_BB_D_DD2_G_1_N + 265.46 *
```

```
   Q_BB_D_DD2_G_1_S + 126.16 * Q_BB_D_DD2_G_2_E + 64.95999999999999 *
   Q_BB_D_DD2_G_2_N + 228.8 * Q_BB_D_DD2_G_2_S + 101.48 * Q_BB_D_DD2_G_3_E +
102.63 *
   Q_BB_D_DD2_G_3_N + 242.08 * Q_BB_D_DD2_G_3_S + 110.71 *
   Q_BB_D_DD2_G_4_E + 87.04000000000001 * Q_BB_D_DD2_G_4_N + 209.16 *
   Q_BB_D_DD2_G_4_S + 93.09999999999999 * Q_BB_D_DD2_G_5_E + 105.95 *
   Q_BB_D_DD2_G_5_N + 190.11 * Q_BB_D_DD2_G_5_S + 85.75 * Q_BB_D_DD2_G_6_E
   + 131.07 * Q_BB_D_DD2_G_6_N + 178.13 * Q_BB_D_DD2_G_6_S + 23.82 *
   Q_BB_D_DD2_G_7_E + 163.4 * Q_BB_D_DD2_G_7_N + 177.7 * Q_BB_D_DD2_G_7_S +
   74.99 * Q_BB_D_DD2_G_8_E + 186.21 * Q_BB_D_DD2_G_8_N + 115.91 *
   Q_BB_D_DD2_G_8_S + 130.49 * Q_BB_D_DD2_G_9_E + 206.998 *
   Q_BB_D_DD2_G_9_N + 129.83 * Q_BB_D_DD2_G_9_S + 116.48 *
   Q_BB_D_DD2_G_10_E + 242.075 * Q_BB_D_DD2_G_10_N + 88.99 *
   Q_BB_D_DD2_G_10_S + 147.815 * Q_BB_D_DD2_G_11_E + 281.05 *
   Q_BB_D_DD2_G_11_N + 69.23 * Q_BB_D_DD2_G_11_S + 58.17 *
   Q_BB_D_DD2_G_12_E + 240.92 * Q_BB_D_DD2_G_12_N + 161.52 *
   Q_BB_D_DD2_G_12_S + 166.29 * Q_BB_D_DD2_G_13_E + 275.28 *
   Q_BB_D_DD2_G_13_N + 51.1 * Q_BB_D_DD2_G_13_S + 202.09 *
   Q_BB_D_DD2_G_14_E + 286.97 * Q_BB_D_DD2_G_14_N + 98.88 *
   Q_BB_D_DD2_G_14_S + 230.67 * Q_BB_D_DD2_G_15_E + 292.31 *
   Q_BB_D_DD2_G_15_N + 235.29 * Q_BB_D_DD2_G_15_S - CFUEL_DD2 = 0 ;
   [_750] 91.17 * Q_BB_D_DD3_G_1_E + 17.87 * Q_BB_D_DD3_G_1_N + 153.53 *
   Q_BB_D_DD3_G_1_S + 72.97 * Q_BB_D_DD3_G_2_E + 37.57 * Q_BB_D_DD3_G_2_N +
   132.32 * Q_BB_D_DD3_G_2_S + 58.69 * Q_BB_D_DD3_G_3_E + 59.36 *
   Q_BB_D_DD3_G_3_N + 140 * Q_BB_D_DD3_G_3_S + 64.03 * Q_BB_D_DD3_G_4_E +
   50.34 * Q_BB_D_DD3_G_4_N + 120.97 * Q_BB_D_DD3_G_4_S + 53.85 *
   Q_BB_D_DD3_G_5_E + 61.28 * Q_BB_D_DD3_G_5_N + 109.95 * Q_BB_D_DD3_G_5_S
   + 49.59 * Q_BB_D_DD3_G_6_E + 75.8 * Q_BB_D_DD3_G_6_N + 103.02 *
   Q_BB_D_DD3_G_6_S + 13.78 * Q_BB_D_DD3_G_7_E + 94.51000000000001 *
   Q_BB_D_DD3_G_7_N + 102.77 * Q_BB_D_DD3_G_7_S + 43.37 * Q_BB_D_DD3_G_8_E
   + 107.7 * Q_BB_D_DD3_G_8_N + 67.04000000000001 * Q_BB_D_DD3_G_8_S +
   75.47 * Q_BB_D_DD3_G_9_E + 119.72 * Q_BB_D_DD3_G_9_N + 75.08 *
   Q_BB_D_DD3_G_9_S + 67.37000000000001 * Q_BB_D_DD3_G_10_E + 140 *
   Q_BB_D_DD3_G_10_N + 51.47 * Q_BB_D_DD3_G_10_S + 85.49 *
   Q_BB_D_DD3_G_11_E + 162.55 * Q_BB_D_DD3_G_11_N + 40.04 *
   Q_BB_D_DD3_G_11_S + 33.65 * Q_BB_D_DD3_G_12_E + 139.34 *
   Q_BB_D_DD3_G_12_N + 93.42 * Q_BB_D_DD3_G_12_S + 96.18000000000001 *
   Q_BB_D_DD3_G_13_E + 159.2 * Q_BB_D_DD3_G_13_N + 29.55 *
   Q_BB_D_DD3_G_13_S + 116.68 * Q_BB_D_DD3_G_14_E + 165.97 *
   Q_BB_D_DD3_G_14_N + 57.19 * Q_BB_D_DD3_G_14_S + 133.41 *
   Q_BB_D_DD3_G_15_E + 169.06 * Q_BB_D_DD3_G_15_N + 136.08 *
   Q_BB_D_DD3_G_15_S - CFUEL_DD3 = 0 ;
   [_751] 89.68000000000001 * Q_BB_D_DD4_G_1_E + 17.57 * Q_BB_D_DD4_G_1_N +
   151.022 * Q_BB_D_DD4_G_1_S + 71.77 * Q_BB_D_DD4_G_2_E + 36.96 *
   Q_BB_D_DD4_G_2_N + 130.16 * Q_BB_D_DD4_G_2_S + 57.73 * Q_BB_D_DD4_G_3_E
   + 58.39 * Q_BB_D_DD4_G_3_N + 137.72 * Q_BB_D_DD4_G_3_S + 62.99 *
   Q_BB_D_DD4_G_4_E + 39.15 * Q_BB_D_DD4_G_4_N + 119 * Q_BB_D_DD4_G_4_S +
   52.97 * Q_BB_D_DD4_G_5_E + 60.28 * Q_BB_D_DD4_G_5_N + 108.16 *
   Q_BB_D_DD4_G_5_S + 48.78 * Q_BB_D_DD4_G_6_E + 74.56999999999999 *
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Q_BB_D_DD4_G_6_N + 101.34 * Q_BB_D_DD4_G_6_S + 13.55 * Q_BB_D_DD4_G_7_E
+ 92.95999999999999 * Q_BB_D_DD4_G_7_N + 101.09 * Q_BB_D_DD4_G_7_S +
42.66 * Q_BB_D_DD4_G_8_E + 105.94 * Q_BB_D_DD4_G_8_N + 65.94 *
Q_BB_D_DD4_G_8_S + 74.24 * Q_BB_D_DD4_G_9_E + 117.76 * Q_BB_D_DD4_G_9_N
+ 73.86 * Q_BB_D_DD4_G_9_S + 66.27 * Q_BB_D_DD4_G_10_E + 137.72 *
Q_BB_D_DD4_G_10_N + 50.62 * Q_BB_D_DD4_G_10_S + 84.09 *
Q_BB_D_DD4_G_11_E + 159.89 * Q_BB_D_DD4_G_11_N + 39.385 *
Q_BB_D_DD4_G_11_S + 33.09 * Q_BB_D_DD4_G_12_E + 137.06 *
Q_BB_D_DD4_G_12_N + 91.90000000000001 * Q_BB_D_DD4_G_12_S +
94.59999999999999 * Q_BB_D_DD4_G_13_E + 156.6 * Q_BB_D_DD4_G_13_N +
29.071 * Q_BB_D_DD4_G_13_S + 114.97 * Q_BB_D_DD4_G_14_E + 163.25 *
Q_BB_D_DD4_G_14_N + 56.253 * Q_BB_D_DD4_G_14_S + 131.23 *
Q_BB_D_DD4_G_15_E + 166.297 * Q_BB_D_DD4_G_15_N + 133.86 *
Q_BB_D_DD4_G_15_S - CFUEL_DD4 = 0 ;
[_752] 124.15 * Q_BB_D_DD5_G_1_E + 24.33 * Q_BB_D_DD5_G_1_N + 209.07 *
Q_BB_D_DD5_G_1_S + 99.37000000000001 * Q_BB_D_DD5_G_2_E + 51.16 *
Q_BB_D_DD5_G_2_N + 180.2 * Q_BB_D_DD5_G_2_S + 79.92 * Q_BB_D_DD5_G_3_E +
80.83 * Q_BB_D_DD5_G_3_N + 190.66 * Q_BB_D_DD5_G_3_S + 87.2 *
Q_BB_D_DD5_G_4_E + 68.56 * Q_BB_D_DD5_G_4_N + 164.74 * Q_BB_D_DD5_G_4_S
+ 73.33 * Q_BB_D_DD5_G_5_E + 83.45 * Q_BB_D_DD5_G_5_N + 149.73 *
Q_BB_D_DD5_G_5_S + 67.53 * Q_BB_D_DD5_G_6_E + 103.23 * Q_BB_D_DD5_G_6_N
+ 140.29 * Q_BB_D_DD5_G_6_S + 18.76 * Q_BB_D_DD5_G_7_E + 128.7 *
Q_BB_D_DD5_G_7_N + 139.95 * Q_BB_D_DD5_G_7_S + 59.06 * Q_BB_D_DD5_G_8_E
+ 146.66 * Q_BB_D_DD5_G_8_N + 91.29300000000001 * Q_BB_D_DD5_G_8_S +
102.78 * Q_BB_D_DD5_G_9_E + 163.03 * Q_BB_D_DD5_G_9_N + 102.25 *
Q_BB_D_DD5_G_9_S + 91.75 * Q_BB_D_DD5_G_10_E + 190.66 *
Q_BB_D_DD5_G_10_N + 70.09 * Q_BB_D_DD5_G_10_S + 116.42 *
Q_BB_D_DD5_G_11_E + 221.35 * Q_BB_D_DD5_G_11_N + 54.52 *
Q_BB_D_DD5_G_11_S + 45.82 * Q_BB_D_DD5_G_12_E + 189.75 *
Q_BB_D_DD5_G_12_N + 127.21 * Q_BB_D_DD5_G_12_S + 130.97 *
Q_BB_D_DD5_G_13_E + 216.8 * Q_BB_D_DD5_G_13_N + 40.25 *
Q_BB_D_DD5_G_13_S + 159.17 * Q_BB_D_DD5_G_14_E + 226.01 *
Q_BB_D_DD5_G_14_N + 77.87000000000001 * Q_BB_D_DD5_G_14_S + 181.68 *
Q_BB_D_DD5_G_15_E + 230.22 * Q_BB_D_DD5_G_15_N + 185.31 *
Q_BB_D_DD5_G_15_S - CFUEL_DD5 = 0 ;
[_753] 124.05 * Q_BB_D_DD6_G_1_E + 24.3 * Q_BB_D_DD6_G_1_N + 208.91 *
Q_BB_D_DD6_G_1_S + 99.28 * Q_BB_D_DD6_G_2_E + 51.12 * Q_BB_D_DD6_G_2_N +
180.06 * Q_BB_D_DD6_G_2_S + 79.86 * Q_BB_D_DD6_G_3_E + 80.76000000000001
* Q_BB_D_DD6_G_3_N + 190.5 * Q_BB_D_DD6_G_3_S + 87.13 * Q_BB_D_DD6_G_4_E
+ 68.5 * Q_BB_D_DD6_G_4_N + 164.6 * Q_BB_D_DD6_G_4_S + 73.27 *
Q_BB_D_DD6_G_5_E + 83.38 * Q_BB_D_DD6_G_5_N + 147.61 * Q_BB_D_DD6_G_5_S
+ 67.48 * Q_BB_D_DD6_G_6_E + 103.15 * Q_BB_D_DD6_G_6_N + 140.18 *
Q_BB_D_DD6_G_6_S + 18.74 * Q_BB_D_DD6_G_7_E + 128.59 * Q_BB_D_DD6_G_7_N
+ 139.84 * Q_BB_D_DD6_G_7_S + 59.01 * Q_BB_D_DD6_G_8_E + 146.54 *
Q_BB_D_DD6_G_8_N + 91.22 * Q_BB_D_DD6_G_8_S + 102.69 * Q_BB_D_DD6_G_9_E
+ 162.9 * Q_BB_D_DD6_G_9_N + 102.17 * Q_BB_D_DD6_G_9_S +
91.68000000000001 * Q_BB_D_DD6_G_10_E + 190.5 * Q_BB_D_DD6_G_10_N +
54.47 * Q_BB_D_DD6_G_10_S + 116.32 * Q_BB_D_DD6_G_11_E + 221.18 *
Q_BB_D_DD6_G_11_N + 54.48 * Q_BB_D_DD6_G_11_S + 45.78 *
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   Q_BB_D_DD6_G_12_E + 189.6 * Q_BB_D_DD6_G_12_N + 127.12 *
   Q_BB_D_DD6_G_12_S + 130.87 * Q_BB_D_DD6_G_13_E + 216.64 *
   Q_BB_D_DD6_G_13_N + 40.21 * Q_BB_D_DD6_G_13_S + 159.04 *
   Q_BB_D_DD6_G_14_E + 225.84 * Q_BB_D_DD6_G_14_N + 77.81 *
   Q_BB_D_DD6_G_14_S + 181.53 * Q_BB_D_DD6_G_15_E + 230.04 *
   Q_BB_D_DD6_G_15_N + 185.17 * Q_BB_D_DD6_G_15_S - CFUEL_DD6 = 0 ;
   [_766] 30 * DGDD_DD1_E_1 + 30 * DGDD_DD1_E_2 + 30 * DGDD_DD1_N_1 + 30 *
   DGDD_DD1_N_2 + 30 * DGDD_DD1_S_1 + 30 * DGDD_DD1_S_2 - CINC_DD1 = 945 ;
   [_767] 21 * DGDD_DD2_E_1 + 21 * DGDD_DD2_E_2 + 21 * DGDD_DD2_N_1 + 21 *
   DGDD_DD2_N_2 + 21 * DGDD_DD2_S_1 + 21 * DGDD_DD2_S_2 - CINC_DD2 = 2856 ;
   [_768] 15 * DGDD_DD3_E_1 + 15 * DGDD_DD3_E_2 + 15 * DGDD_DD3_N_1 + 15 *
   DGDD_DD3_N_2 + 15 * DGDD_DD3_S_1 + 15 * DGDD_DD3_S_2 - CINC_DD3 = 2520 ;
   [_769] 22 * DGDD_DD4_E_1 + 22 * DGDD_DD4_E_2 + 22 * DGDD_DD4_N_1 + 22 *
   DGDD_DD4_N_2 + 22 * DGDD_DD4_S_1 + 22 * DGDD_DD4_S_2 - CINC_DD4 = 16632
   ;
   [_770] 17 * DGDD_DD5_E_1 + 17 * DGDD_DD5_E_2 + 17 * DGDD_DD5_N_1 + 17 *
   DGDD_DD5_N_2 + 17 * DGDD_DD5_S_1 + 17 * DGDD_DD5_S_2 - CINC_DD5 = 17340
   ;
   [_771] 17 * DGDD_DD6_E_1 + 17 * DGDD_DD6_E_2 + 17 * DGDD_DD6_N_1 + 17 *
   DGDD_DD6_N_2 + 17 * DGDD_DD6_S_1 + 17 * DGDD_DD6_S_2 - CINC_DD6 = 357 ;
   [_772] CINCT - CINC_DD1 - CINC_DD2 - CINC_DD3 - CINC_DD4 - CINC_DD5 -
   CINC_DD6 = 0 ;
   [_773] CTCTRUCKS - CFUELTRUCKSTOTAL = 111344.03 ;
   [_774] CFUELTRUCKSTOTAL - 25.7 * XF_E - 28.52 * XF_N - 8.442 * XF_S = 0
   ;
   [_780] XF_E - 80 * NOOFTRUCKSPERDUMPSITE_E <= 0 ;
   [_781] XF_N - 60 * NOOFTRUCKSPERDUMPSITE_N <= 0 ;
   [_782] XF_S - 100 * NOOFTRUCKSPERDUMPSITE_S <= 0 ;
   [_783] NOOFTRUCKSPERDUMPSITE_E + NOOFTRUCKSPERDUMPSITE_N +
   NOOFTRUCKSPERDUMPSITE_S = 14 ;
    @GIN( NOOFTRUCKSPERDUMPSITE_E); @GIN(
      NOOFTRUCKSPERDUMPSITE_N); @GIN( NOOFTRUCKSPERDUMPSITE_S);
 END
```