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Extracting Tehran Refuse Collection Truck Cycle and Estimating the Braking Energy

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Driving cycle is used to assess fuel consumption, pollutant emissions and performance of the vehicle. The aim of this paper is to extract the driving cycle for refuse collection truck and estimate its braking energy. For this purpose, after selecting the target truck and geographic area, the equipment needed to measure the required variables were prepared and mounted on the truck. Then, the actual data were collected from the performance of the target Truck while performing its mission. Since the amount of braking energy depends on the speed, truck mass and road grade, the speed of the vehicle is measured simultaneously with the truck mass and road grade. The collected data are then processed and subdivided into micro-trips. The micro-trips are clustered according to the number of state spaces using the K-Means algorithm. Next, the representative micro trips are selected from within the clusters and the final driving cycle is generated. The representative driving cycle shows that the truck speed is zero at 48% of the working time. Finally, the amount of braking power and accumulative energy in the driving cycle is calculated.

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1. Introduction

With the growth of urbanization culture and the increase in the size and population of cities and the need to improve the quality level of environmental standards, it is necessary to mechanize urban services. In this regard, the number of municipal service trucks used to collect refuses in cities is increasing. For example, the metropolis of Tehran produces more than 9 thousand tons of solid refuse per day, which is much higher than the world standard. The city has more than 1,500 municipal service trucks, including refuse collection trucks, construction trucks, multi-function road sweeper trucks, road guardrail washing trucks, refuse box washing trucks, water tank trucks, refuse transfer trucks and the like. Refuse collection trucks travel through the residential areas and streets, stop at loading stations and collect refuse by a mechanized system. The distance between loading stations varies according to population density, lifestyle and urban infrastructures. In Tehran metropolis, the distance between loading stations varies from 100 to 250 meters. In other words, refuse collection trucks at a maximum of every 250 meters must have a stop to perform the loading process. Figure 1 shows the pattern of the refuse collection driving cycle at working time.

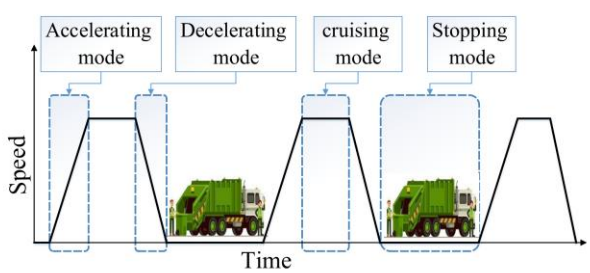

Figure 1: Pattern of the refuse collection driving cycle

A driving cycle is a series of data points representing the speed of a vehicle versus time[1]. As shown in figure 1, the refuse collection truck driving cycle includes acceleration, cruise, deceleration, and stop at loading station modes, which are repeated throughout the driving cycle with a short interval. Research shows that vehicle fuel consumption, emissions, amount of braking energy are influenced by the driving cycle and operating conditions of the vehicle[2]. During the refuse collection truck driving cycle, a large percentage of the truck's kinetic energy is lost in the braking mode by the frictional braking system. The hydraulic regenerative braking system is one of the technologies applied to recover the braking energy of light-duty and medium-duty trucks that have many stops at their driving cycles[3]. This system is most efficient in trucks that have many stops in their working time. The amount of energy recovered during braking mode depends on the mass of the truck, road grade and the speed. To estimate the amount of regenerative braking energy, it is necessary to extract the driving cycle. West Virginia University researchers developed the New York Garbage Truck Cycle (NYGTC) by recording the characteristics of their typical operation[4]. A speed versus time plot of the NYGTC is shown in Figure 2.

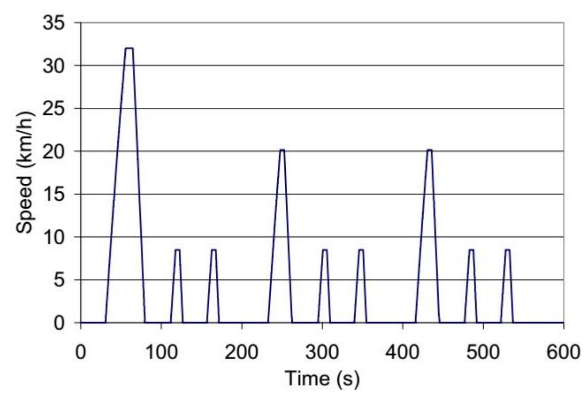

Figure 2: New York Garbage Truck Cycle (NYGTC) [4]

This cycle consists of 9 stops, 3 of which are long relating to the loading process. This cycle is based on a single day’s worth of data collected from one refuse truck that operated in New York City[5]. This cycle is often used for evaluating fuel economy and emissions in the most severe refuse collection service with very low average speed and very frequent stops. In 2005, researchers at the Ohio State University Automotive Research Center extracted a driving and duty cycle of refuse collection truck[6]. In this study, cities from the Minneapolis, Florida, Texas, and Arizona were selected for data collection. In 2014, Frank Bender derived the

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refuse collection truck driving cycle for the city of Stuttgart in Germany[7]. this cycle considers not only the time-velocity signal, but also additional signals such as the road grade and the truck mass. In 2015, Fotouhi extracted the driving cycle of Tehran city for passenger cars[8]. Driving cycle is one of the important input parameters used in system design of vehicle and simulation by auto manufacturers and research centers. The driving cycle is also used to analyze the application of different urban and interurban fleets and the performance of vehicle systems. Based on actual tests, the driving cycle has a great effect on the simulation results[2, 7], so it is not possible to use the driving cycle of a specific vehicle in one city or country for another type of vehicle in another country or city.

The purpose of this study is to extract the driving cycle and estimate the amount of braking power and energy in the refuse collection trucks. The most common standard driving cycles in the world only show car speed over time, but due to the high impact of truck mass and road grade parameters on the amount of braking energy, the speed of the truck is measured simultaneously with the truck mass and the road grade. in the first step, the truck type and geographic area were determined. Then the data acquisition equipment was mounted on the truck and real world data were collected. In the next step, the data were divided into micro trips. The micro trips were clustered according to the number of state spaces. Then the representative micro-trips of clusters were selected and the final driving cycle was generated. Finally, the amount of braking energy and accumulative energy in the driving cycle was estimated.

2. Data collection

The type of vehicle and the geographical area have a significant effect on the driving cycle, so the vehicle type and target city must be selected in the first step. In this study, Tehran was selected as the target city, because it has the largest refuse collection truck fleet in the country. The city of Tehran is divided into 22 zones and 124 districts, and the collection of urban solid refuse in each district is assigned to a private service company. Refuse collection trucks in different areas perform almost the same mission, with the only difference being in the distance of collection districts from the unloading site as well as the road grade of the streets in different districts and zones. The north of Tehran is closer to the mountains and the streets and alleys usually have a medium and high grade. The south of Tehran however is smoother. Since the data collection path must be a good representative of the traveled paths, zone 1 in Tehran, comprising 10 districts, was selected as the data collection area. In Tehran, because of the heavy traffic jam and the low width of the roads, Class 3 trucks are used to collect urban refuses. Field research and counselling with several service companies and manufacturers of refuse collection equipment and chassis show that most of the trucks used for collecting urban refuses are Isuzu trucks with gross vehicle mass 6000 Kg. In this study, the 6-ton Isuzu truck was selected as the target vehicle. its specifications are shown in table 1.

Table 1: Isuzu truck specification

Engine	Description	2999 cc - 4 cylinder.
	Max. Power	120kW @ 2800 rpm
	Max Torque	382 Nm @ 1600 rpm
Transmission	design	Manual -5 Speed
	Gear ratios	4.2,3,1.7,1,075
	Differential	4.1
Vehicle	Gross mass	6000 kg
	Air drag	0.75
	Front Area	4.3 m2
	Tire radius	0.43 m

In this study, the driving cycle was extracted simultaneously with the road grade cycle and the truck mass cycle. Therefore, three variables of vehicle speed, road grade and truck mass need to be measured and stored during the truck activity.

car-chasing and on-board measurements are two ways used to collect vehicle activity over time[9]. In this study, on-board data acquisition was used for six weeks. To measure the speed of the truck, CAN[1] bus information or GPS[2] sensor can be used. Vehicles equipped with CAN bus place variables such as vehicle speed, engine speed, fuel consumption and the like on the CAN

1-Controller Area Network
2- Global Positioning System

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bus. The amount of any variables can be extracted from CAN bus If IP address of the variable is available. This method is more reliable than the GPS sensor with high precision. In this study, since the IP address of the variables was inaccessible to us, the antenna GPS sensor NEO 6M was used. The GPS sensor measures information such as latitude, longitude, altitude, date, time, speed, mileage, and the number of satellites in connection. The latitude and longitude can be used to record the truck's movement on the map and the vehicle's deviation from the route. this GPS sensor measures with an accuracy of two meters.

The GPS sensor, barometer sensor, and tilt sensor can be used to measure the road grade. The GPS sensor calculates the altitude of the truck's position and consequently the road grade, but the GPS estimation is not always reliable. For this reason, a barometer sensor is commonly used. Frank Bender used a barometer sensor to calculate the road grade[3]. In this study, LPS331AP MEMS absolute pressure sensor was used to increase the accuracy of altitude measurement. This sensor uses innovative MEMS technology to provide extremely high pressure resolution, in ultra-compact and thin packages.

The mass of refuse collection truck varies during its mission. The truck is unloaded and weighs the least when traveling from the parking lot to the first loading station. The truck mass increases in any stop at the loading station. The truck collects the urban refuses by the time its capacity is filled. As soon as the tank capacity is filled, the truck travels to the nearest unloading site. At this time, the truck weighs the most. At the unloading site, the trucks are weighed by the railroad scale and then the trucks in turn unload the collected refuse into large trailers. After unloading the refuse, the truck returns to the parking lot or to the urban refuse collection district if its mission is not completed. To measure the truck's mass gain during its mission, special equipment is needed to be mounted on the truck. Another method is to measure the mass of refuse boxes at each loading station. The fact is that the preparation and installation of these types of equipment on truck or weighing of the refuse boxes are time consuming and costly processes. In order to simplify the mass measurement process, the data from the unloading site monitoring center were used. The monitoring center records the mass of the refuse collected by trucks. Using the total mass of the collected refuse and the number of stops at loading station, the average mass gain for each loading can be calculated. Truck stops include stops at traffic lights, traffic jams and loading station. At loading station, the driver activates the PTO shaft to operate auxiliary system mechanisms. The PTO shaft is activated by a lever from inside the driver's cab. A distance ultrasonic sensor was used to determine the position of the lever. Using the information from this sensor, the stops at loading station can be distinguished from other stops.

An electrical board was designed and built as data acquisition system to receive, process, and store the output signals of the GPS sensor, the barometer sensor, and the distance sensor. The electrical board consists of a processing unit, data logger, 20*4 LCD, Flash memory and battery pack. The output signals with adjustable frequency are stored in the flash memory and viewed online by the LCD. The sensors, and the electrical board are powered by a 5000 mAh battery pack. This battery pack can supply the energy needed for continuous data acquisition process for 60 hours. The electrical board, LCD and battery pack are located inside an IP66 waterproof plastic electric box. Figure 3 illustrates the data acquisition system.

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Figure 3: Data acquisition system

Sensors, wires, and electric box should be mounted in the right place in such a way that they will not interfere with the driver, operators or the auxiliary system function. All the equipment should be resistant to vibration, temperature changes, and weather changes so as not to disturb the data acquisition process.

3. Data Processing:

3.1. Data pre-processing:

There may be always minor errors in the collected data. Before analyzing the data and extracting the driving cycle, the quality of the collected data should be evaluated and their possible errors corrected. For example, to calculate the 2-D position (latitude and longitude) and to track the truck's movement, a GPS receiver must be locked on to the signal of at least 3 satellites. With 4 or more satellites, the receiver can determine the 3-D position (latitude, longitude, and altitude). Therefore, the number of satellites connected with the GPS sensor needs to be checked and the areas that do not meet this requirement are deleted. Table 2 shows a sample of collected data within half a working day.

According to the data collected for speed and height variables within half a working day, the speed and height versus time graph of the truck is shown in figure 4.

According to the graph, the working conditions of the refuse truck can be divided into five distinct state spaces, respectively.

1- Travelling from the parking lot to the first loading station

In this state, the truck is empty and travels from the parking lot to the first loading station. High average speed, low mass, and few stops are the features of this state.

Table 2: A sample of collected data

Milli-S.	date Time	Lat.	Lng.	Speed	Alt.	Sat. Num	Slop
3526	"2019/9/3 20:58:24"	3547.277	5129.525	0	1534.8	9	0.65
4525	"2019/9/3 20:58:25"	3547.277	5129.52512	0	1534.8	9	0.65
5524	2019/9/3 20:58:26"	3547.277	5129.52516	0	1534.8	9	0.65
6523	2019/9/3 20:58:27"	3547.277	5129.5252	0	1534.8	9	0.65
7524	"2019/9/3 20:58:28"	3547.277	5129.52522	0	1534.7	9	0.65
8526	"2019/9/3 20:58:29"	3547.277	5129.52526	0	1534.7	9	0.65
9522	"2019/9/3 20:58:30"	3547.277	5129.52528	0	1534.6	9	0.65
10521	2019/9/3 20:58:31"	3547.277	5129.52531	0	1534.5	9	0.65
11521	2019/9/3 20:58:32"	3547.277	5129.52532	0	1534.4	9	0.65
12520	2019/9/3 20:58:33"	3547.277	5129.52531	0	1534.4	9	0.65
13519	2019/9/3 20:58:34"	3547.277	5129.52534	0	1534.5	9	0.65
14519	2019/9/3 20:58:35"	3547.277	5129.52538	0	1534.5	9	0.65
15519	2019/9/3 20:58:36"	3547.277	5129.52543	0	1534.5	9	0.65
16518	2019/9/3 20:58:37"	3547.277	5129.52547	0	1534.6	9	0.65
17517	2019/9/3 20:58:38"	3547.277	5129.52553	0	1534.7	9	0.65
18516	2019/9/3 20:58:39"	3547.277	5129.52559	0	1534.7	9	0.65
19527	2019/9/3 20:58:40"	3547.277	5129.52564	0	1534.7	9	0.65
20515	2019/9/3 20:58:41"	3547.277	5129.5257	0	1534.6	9	0.65

2- Urban refuse collection

In this state, the truck stops at special stations to collect unban refuse. To collect the urban refuse, the PTO shaft is activated and the energy required to move the auxiliary system mechanisms is supplied by the hydraulic pump. low average speed, long and repetitive stops, mass gain per stop at loading station, and PTO shaft activity are the features of this state.

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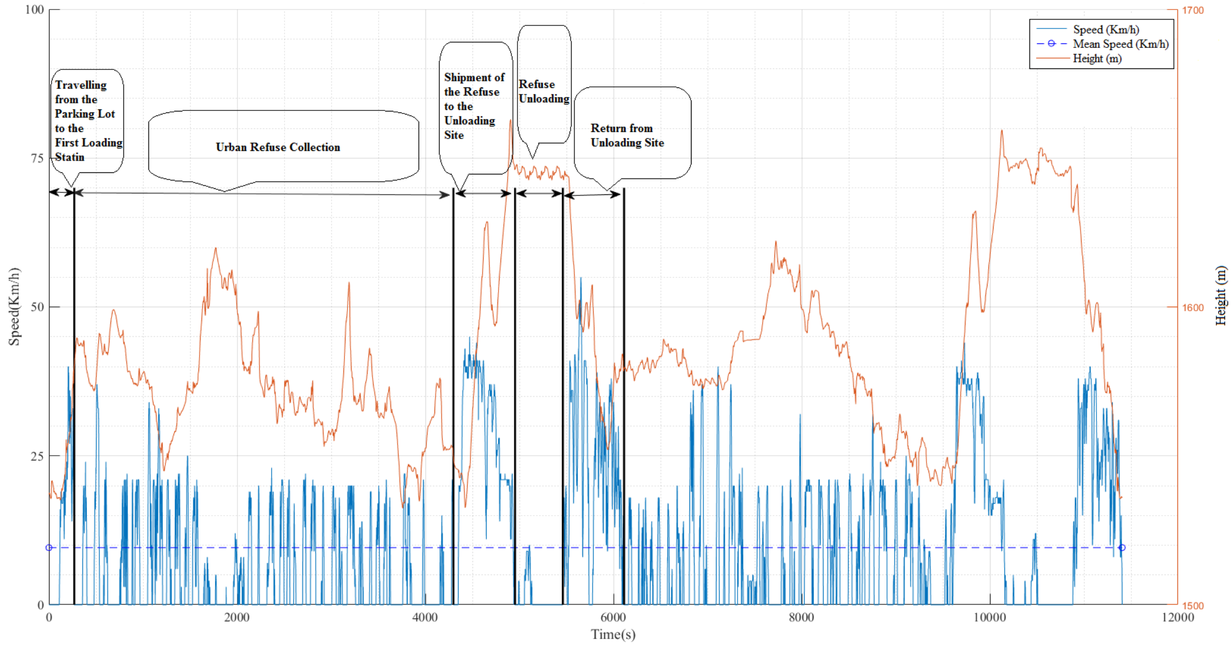

Figure 4: Speed and height versus time graph of refuse collection truck within half a working day

3- Shipment of the refuse to the unloading site

In this state, the tank capacity of the truck is filled and the truck moves to the unloading site. High average speed, high mass, few stops are the features of this state.

4- Refuse unloading

In this state, the truck enters the unloading site and the gross mass of the truck is weighed by the railroad scale. The urban refuse is then unloaded into large trailers in turn at special stations. The energy required to unload the refuse is provided by the PTO shaft. Weight loss of the truck from gross mass to curb mass, PTO shaft activity, and long stop are the features of this state.

5- Return from unloading site

In this state, the truck moves from the unloading site to the parking lot or its intended district if its mission is not completed. High speed, few stops and low mass are the features of this state. This state is similar to state 1.

Given the unique mission of the refuse collection truck, the chronological order of these states is almost fixed for Tehran refuse collection fleet and other cities in Iran.

3.2. Statistical Metrics:

At this stage, the statistical metrics for the collected data are defined and their values are calculated. These metrics are used to determine the working conditions of the target vehicle and compare them with the statistical metrics of the extracted driving cycle. The statistical metrics vary according to the type of vehicle and the number of measured variables. Table 3 shows the defined statistical metrics.

Table 3: Statistical Metrics for the collected Data

No.	Statistical Metrics	Description
1	Pct Time Stop	Percent of time when the truck stops
2	Pct Time Acc.	Percent of time when the truck accelerates
3	Pct Time Dec.	Percent of time when the truck deaccelerates
4	Pct Time Cruise	Percent of time when the truck is cruising
5	Max Speed	Maximum speed
6	Mean Speed	Average speed
7	Mean Driving speed	Average speed while driving
8	Max Acceleration	Maximum positive acceleration

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9	Mean Acceleration	Average positive acceleration
10	Max Deceleration	Maximum negative acceleration
11	Mean Deceleration	Average negative acceleration
12	Max pos. Grade	Maximum positive grade
13	Mean pos. Grade	Average positive grade
14	Max neg. grade	Maximum negative grade
15	Mean neg. grade	Average negative grade
16	Average mass gain	Average mass gain for each stop at loading station
17	No. stop per hour	Number of stops per hour
18	No. the PTO activation	Number of stops when the driver activates the PTO shaft
19	Average dis. Refuse boxes	Average distance between refuse boxes
20	Braking En. Per Km	Amount of braking energy per kilometer

For example, the collected data indicates that the refuse collection truck stops within over 48 percent of working time. Figure 5 shows the percentage of driving modes for the collected data.

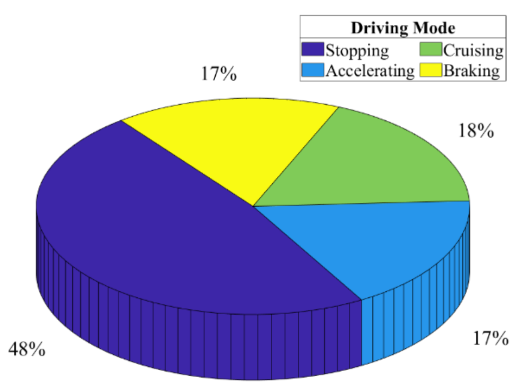

Figure 5: Driving modes of the collected data

According to figure 5, 17 percent of the mission time belongs to accelerating mode, 18 percent to cruising mode, 17 percent to decelerating mode, and 48 percent to stopping mode. Furthermore, in over 70 percent of the stopping mode, the auxiliary system is activated and the hydraulic pump supplies the energy needed to operate the auxiliary hydraulic cylinders.

4. Driving cycle extraction:

In the research carried out to extract the driving cycle[7, 8], the data are analyzed in various ways. One of the most common methods is to divide the data into micro-trips and classify similar micro-trips using statistical classification tools. A micro-trip is the interval of two consecutive stops in the driving cycle, including stopping, accelerating, cruising and braking mod[10]. Each micro-trip has unique features. The characteristics of each micro-trip are determined by various parameters such as mean speed, mean driving speed, idle time percent, average acceleration, average deceleration, etc. In this study, in order to determine the characteristics of each micro-trip, in addition to vehicle motion parameters, the parameters of road conditions and vehicle condition such as road grade and vehicle mass were used. Using the characteristics of each micro-trip, all similar micro-trips can be clustered into distinct clusters. K-Means algorithm is one of the most common tools for data classification, which is used in the extraction of driving cycles. The inputs of this algorithm are the quantity of clusters and the characteristics of each micro trip. The outputs are the cluster number for each micro trip and the center of the clusters. As mentioned above, the working conditions of the refuse truck consist mainly of five state spaces where the characteristics of states one and five are similar. In this study, the micro trips were clustered in 4 clusters. average driving speed, idle time percent, PTO shaft activity time percent, average road grade, and truck mass were used as the characteristics of each micro trip.

After clustering of micro trips using MATLAB software, the number of micro trips and the total time of each cluster were calculated. according to the driving cycle time, the time share of each cluster in the driving cycle was determined. The duration of the driving cycle should be able to represent all the state spaces, and take the least possible time in a computer simulation or dynamometer testing. Exploring the collected data shows that the average time for the entire five state spaces is approximately 120 minutes. In this study, about a quarter of this time was selected as the duration of the driving cycle, which corresponds with the global standard driving cycle time.

In the next step, the representative micro trips were selected from each cluster. The center of each cluster has the most similarity to the characteristics of each cluster. Therefore, the micro trips closest to the center of the cluster were selected as representative ones. Figure 5 shows an example of the representative micro trips for the clusters.

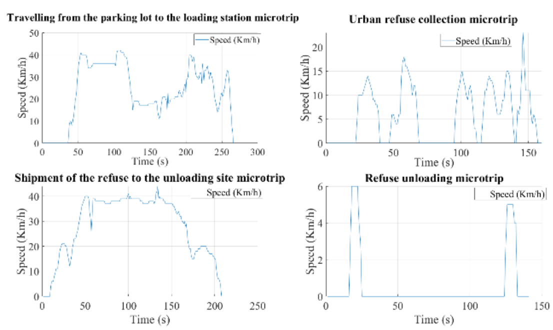

Figure 5: An example of the representative micro trips for the clusters.

Selection of representative micro trips from each cluster continues as long as the time share of that cluster is completed in the driving cycle. Given that the state spaces are in chronological order, the selected micro-trips construct the driving cycle in accordance with mentioned chronological order. Figure 6 shows the generated driving cycle together with the truck mass.

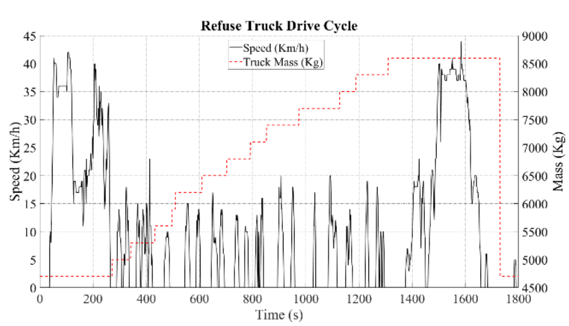

Figure 6: Generated refuse truck driving cycle together with the truck mass

4.1. Accuracy of the driving cycle:

In this study, the above mentioned statistical metrics were used to verify the accuracy of the driving cycle. First, the values of the statistical metrics for the extracted driving cycle were calculated. Then they were compared with the values of entire collected data. This comparison showed that the extracted driving cycle intersects by 92% with the collected data.

5. Braking Energy:

As mentioned, 17 percent of the truck mission time belongs to braking mode. So, a large percentage of the internal combustion engine energy is wasted during the braking mode. The results of this study also show that mass gain of truck during its mission has a significant effect on braking power. Figure 7 shows the amount of braking power in the extracted driving cycle.

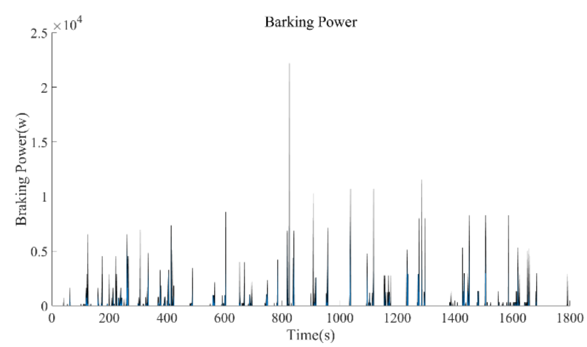

Figure 7: Braking power in Tehran refuse collection truck

As shown in figure 7, concurrent with an increase the mass of the truck at the time of the collection state, the amount of braking power and consequently the amount of braking energy increase. Braking energy can be recovered and reused in acceleration mode using regenerative braking system technology. Figure 8 shows the amount of brake energy accumulated in the extracted driving cycle.

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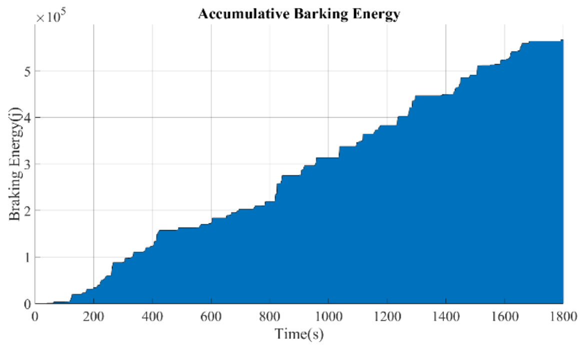

Figure 8: Accumulative braking energy in Tehran refuse collection truck.

using regenerative braking system technology, a low percentage of braking energy is wasted by air drag, rolling resistance and power transmission system, and the rest can be recovered and reused[11].

Conclusion:

This study developed a representative driving cycle of refuse collection truck for the city of Tehran. It included not only the standard driving cycle, but also mass and road grade. The extracted driving is a transient driving cycle similar to FTP-75 driving cycles, which is experimental based and are more reflecting the actual driving conditions. To extract the driving cycle, the real world data from zone 1 in Tehran were used. Generated driving cycle shows that 17 percent of the refuse truck mission time belongs to accelerating mode, 18 percent to cruising mode, 17 percent to decelerating mode, and 48 percent to stopping mode. This cycle can be used to examine vehicle fuel consumption and emissions, optimize the auxiliary system performance and estimate the braking energy.

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