Evaluation of a vehicle powertrain fitness to application using driving cycle by Monte Carlo method

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ABSTRACT

Automotive powertrains are designed or selected according to power demand analysis and simulations which are closely related to the vehicle driving pattern. When a car is utilized for a non-purposed application, its driving cycle is different so the design targets are not met. It results in lower efficiency, waste of resources due to over or under engineering and lack of satisfaction. In this study, a typical passenger car which is converted to a taxi is investigated for its design fitness. The driving cycle of the taxi is a combination of long modal trips which are assembled by large sets of transient micro-trips. It is constructed using actual data collected by a GPS and data logger. After filtering noises by LOWESS technique, statistical distribution of the dataset is verified so that Monte Carlo method can be implemented. Based on the acceleration results of the simulation, power demands of the vehicle and duty cycles can be derived and compared to the engine characteristics. The discrepancies indicate that the design of the powertrain does not match its application.

KEY WORDS: Automotive powertrain, Driving cycle, Monte Carlo method, Simulation

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1. INTRODUCTION

Standard driving cycles do not specify vehicle types and applications. Synthetic types of them are mostly constructed in order to verify powertrain design and compatibility through virtual analysis and simulations. On the other hand, representative driving cycles are developed in order to investigate emissions, fuel consumptions and legislations. (Tong H. Y. et al., 1999; Esteves-booth A., 2001; Tzirakis E. et al, 2006)

Basically, some factors including vehicle, driver, traffic, driving route, environment and time of driving are taken into account.(Andre M., 1996) However, the utilization of the vehicle is not explicitly defined. The fact that many vehicles are subjected to unpredicted driving conditions, makes the corresponding drive cycle invalid. Extreme cases happen when for example a delivery van is used for public transport or a SUV is driven inside the urban areas.

In this research, the driving cycle of a passenger car, which is transformed to a taxicab, is investigated. GPS devices are installed on three sample cars and speed data are gathered for similar routes and durations. Since the PDF of the dataset is unknown, a fitting tool should be employed in order to identify the distribution function. For this purpose, the dataset is refined in advance by a smoothing filter so that noises and outliers are totally removed. When the speed measures and profile are recognized, the most probable accelerations as well as the joint distribution of speed and acceleration are obtained through Monte Carlo simulation. The set of parameters including maximum speed and acceleration; and average speed and acceleration are compared to the vehicle speed and acceleration range. It is evident by the result that the powertrain capacity is oversized for the expected performance from the conversion.

2. DATA COLLECTION

Data recording and transmission for coordination and velocity are performed by a Polstar BGDL-100 GPS antenna and a customized data logger. The receiver is installed inside the cabin behind the windscreen and the data logger underneath the dashboard. The supply power of 7.5-35V is provided directly from the battery of the car. Data can be stored in the memory of the device at 1Hz frequency and up to 4GB. Later on, it can be transferred via bluetooth into a text file for interpreting. A sample line of the text file as follows has been translated in Table 1. (Polstar, 2007)

@1 03 02 09/29/2008 13:11:30 +36267648 +059586373 +0002 024092

Validity	NOS	HDOP	UTC Date	UTC Time	Latitude	Longitude	Altitude	Speed
@1	3	2	09/29/2008	13:11:30	36267648	59586373	2	24092

Table 1. GPS data sample

A driving route can be divided into microtrips of short length and linear speed. (Van de Weijer C.J.T., 1997) In each interval, the acceleration is simply obtained by a first degree differential equation for speed to time. Incorporating an IMU (inertial measuring unit) for acceleration measurement can increase the accuracy but requires extra devices such as accelerometers and gyroscopes to record acceleration and rotation rates on three dimensional axis.

By the scope of this study, the accuracy of the calculated acceleration is adequate. Moreover, the simulation technique does not inquire linear relationship and can be implemented on longer intervals. Hence, it is not necessary to collect acceleration data directly and independently by inertial measuring techniques.

The area under study is plain with no significant change in altitude. Therefore two dimensional motion (in latitude and longitude) is sufficient.

The GPS reception in the study zone was evaluated by means of determining the percentage of time the unit calculated the position using different number of satellites. GPS accuracy in determining the position is directly proportional to the number of satellites it locates. (Rodriguez I., 2003) Hence, the more satellites it locates, the more accurate the position is; and the more reliable speed profile is obtained.

Figure 1 shows the proportion of the time each cycle presented in terms of the number of satellites the GPS locates. For A1 and A3 cycles, in more than 90% of the time, number of satellites are greater than 4. Cycle A2 has experienced a lower percentage(78%) which is rectified by withdrawal of the data related to the invalid conditions.

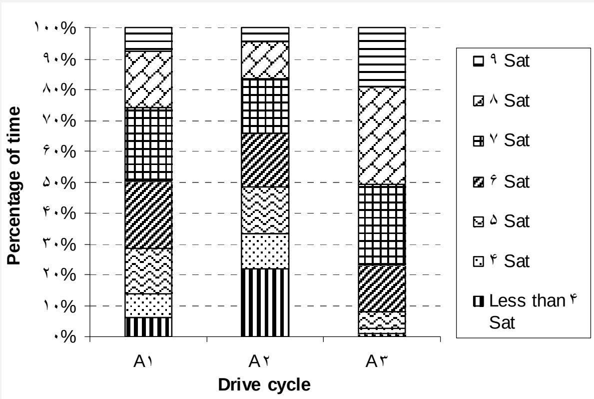


Figure 1. Number of Satellites perceived by the GPS per measurement cycle

2.1 Route selection

The taxi service of this study has a fixed route. At cabstand, taxis pick up passengers in turn and start the trip only when fully loaded. There is no stops on route and all passengers get off at the termination point. This type of transport is popular in the city of Mashhad where this research is undertaken. However, the routes are defined by authorities and cannot be modified.

Based on a comprehensive transportation survey for the city, most passengers commute on a particular route which has been already considered for lightweight underground/tram services. (Sharif Institute of Transport Research, 2003) Nevertheless, the project is yet to be fulfilled and the passengers have to take other options. On the other hand, the expensive fare of taxis as well as waiting times and safety concerns make it undesirable choice in some other parts of the city. Other limitations in selecting a representative route are as follows:

1. GPS receiver cannot communicate with satellites in subways, multi level crossings or condensed urban areas with high buildings.

2. Congestion charging and temporarily traffic regulation in central areas affect the normal transport.
Considering all the requirements and limitations, the driving route is chosen as shown in Figure 2.

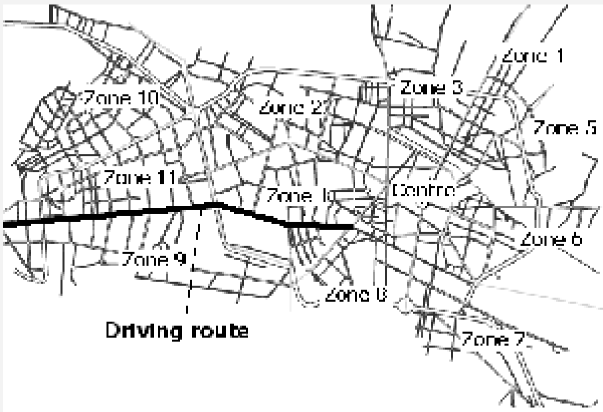


Figure 2. Route path on a map of Mashhad

A summary of the routes measured, containing exact dates, is presented in the table below. The distance driven and the average duration are taken from previous estimates. A taxi service with variable path is also included in the study in order to compare results with fixed route services.

Cycle	Taxi service	Period		Route length	Mean time
		start	end		
A1	Fixed route	29.09.08	30.11.08	14km	30min
A2	Fixed route	29.09.08	14.11.08	14km	30min
A3	Variable	22.12.08	12.02.09	----	----

Table 2. Cycle route data

2.2 Powertrain specification

The prime mover of the converted vehicle originally consists of a 4 cylinder, 1538cc combustion engine with maximum power 65hp at 5000rpm and compression ratio of 7.8:1. The maximum speed at 4th gear is 137km/h.

2.3 Other factors

Driving behavior is classified into skillful and placid, skillful but impassioned and totally awkward. (Andre M., 1996) For taxi drivers, these factors are strictly and regularly inspected by mandatory tests including body and mental health check. Other influences such as the weather and time of driving is also carefully considered by expanding the data collection period into 24 hours a day and a few month duration in autumn and winter. Adverse weather conditions as well as weekends and public holidays are all included so the data set is sufficiently representative and reliable.

3. DATA INTEGRATION

Various algorithms have been already proposed for data integration and driving cycle development. (Schwartz, 1977; Dorobantu R. ,1998) In particular, integration of velocity and acceleration data has been widely discussed. Some algorithms take into account different errors and corrections for 3D models through strapdown mechanisation and Kalman filtering. The differential equation matrices are then solved by Runge-Kutta method. (Welch, G., 2003) In the current study, a simplified algorithm (as shown in Figure 3) is introduced using a simulation technique. The challenging phases of integration are the assumptions for simulation and multi-variable distribution.

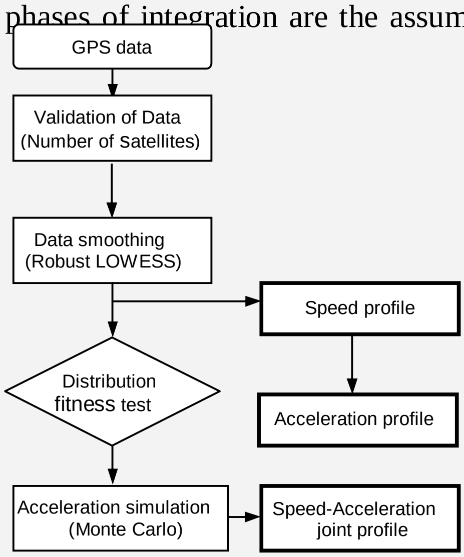


Figure 3. Speed/Acceleration profile algorithm

3.1. Smoothing filter

Discrete data from GPS contains unavoidable noises and errors. Therefore, an initial filtering must be conducted in order to remove the spikes. Two different filters have been tested for this research. The first technique is the popular method which is widely used in driving cycle studies. (Hann D., 2001) Its function weights the measured velocity for a set of 4 points before and 4 points after the time *t* that is to be smoothed.

$$v(t) = \frac{1}{4}\sum_{i=-4}^{4} w\left(\frac{i}{4}\right).\, v(t+i) \qquad (1)$$

$$w(x) = \begin{cases} \frac{15}{16}(1-x^2)^2 & \text{for } x^2 < 1 \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

Figure 1 shows the smoothing result ,v(t) named “filtered data”, for 140 successive moments in cycle A2.

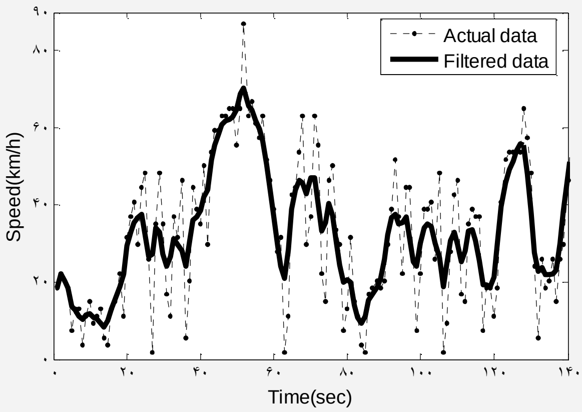


Figure 4. Data smoothing by biweight kernel

The second technique is a robust, locally weighted, scatter plot smoothing or LOWESS by MatLab. It uses locally weighted linear regression to smooth data. In normal LOWESS the weights are given by the tricube function in compare to above technique. (Mathworks Inc., 2004)

$$w_i = \left(۱ - \left| \frac{x - x_i}{dx} \right|^{۳} \right)^{۳} \quad (3)$$

Additionally, a robust procedure removes the influence of outliers with the bisquare function shown below.

$$w_i = \begin{cases} (۱ - (\frac{r_i}{۶MAD})^{۲})^{۲} & |r_i < ۶MAD| \\ ۰ & |r_i \geq ۶MAD| \end{cases} \quad (4)$$

where $MAD = Median(|r|)$.

Using robust LOWESS method (*cftool* in MatLab) the smoothing is administered on the same set of data as shown in Figure 2. The overall pattern looks alike in Figure 4 and 5, however, a mean square error analysis proves that the second technique gives more accurate results. For sample data in Figure 4 and 5, results are obtained as follow:

$$MSE_{۱} = ۱۲۳۷۱ > MSE_{۲} = ۸۴۸۸.۸ \quad (5)$$

where $MSE_{۱}$ is the mean square error for biweight smoothing and $MSE_{۲}$ for robust LOWESS technique. Therefore, the robust LOWESS method is preferred in this research.

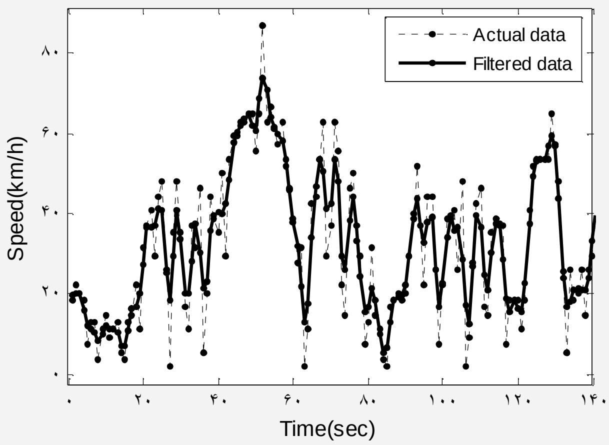


Figure 5. Data smoothing by Robust LOWESS method

3.1. Speed and Acceleration profile

Filtered data can be trusted for cycle development. For A2 cycle, the charts based on smoothed speed data are demonstrated in Appendix 1 and for acceleration in Appendix 2. Since the time scale is too long, three sections are arbitrarily selected. However, the trend line shows that a similar pattern is repeated along the whole time span. This can be justified by the route length of Table 2 and the following arguments.

Average speed for A2 cycle (from dataset) is equal to 27.6km/h and the average alternating time period according to Chart 1 to 3 of Appendix 1, is about 1800 second or half an hour. Therefore, the common equation for distance traveled by the taxi at constant speed, will yield 13.8km for each period close to 14km from Table 2. This is an evidence that the vehicle has an intermittent cycle which is completely in agreement with the fixed route service of the taxi. In contrast, the A3 speed data when plotted against time does not show any particular trend as observed in A1 and A2 cycles.

4. MONTE CARLO SIMULATION

The aim of using Monte Carlo (MC) is to find the most probable acceleration for speed vs. time as a function of the accumulated distribution of the acceleration values to the speed class considered. The MC algorithm is usually defined as follows: (Raychaudhuri S., 2008)

۱. Generate a sample of size n as: $v^1, v^2, ..., v^n$

۲. Calculate $a(v^1), a(v^2), ..., a(v^n)$

۳. Obtain: $ACC = E[a(v)]$, $\overline{ACC} = \frac{a(v^1) + a(v^2) + ... + a(v^n)}{n}$

The key to MC is the initial distribution of the variables which should be identified. It requires a distribution fitness test in advance.

4.1. Distribution fitting

Different distributions can be compared for the fitness to data using *dfittool* in MatLab so that the most appropriate one with the least errors be taken.

At first, a histogram based on filtered data should be produced. This provides a descriptive and graphic representation for the pool of data such as in Figure 6, on which various distribution can be evaluated.

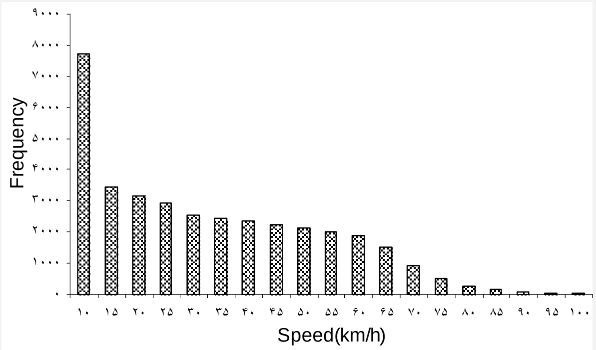


Figure 6. Histogram of A2 sample data

In the present case, a half-normal distribution on the positive horizontal axis has been qualified. Figure 7 shows a plot of the A2 cycle CDF plus optimum distribution fit.

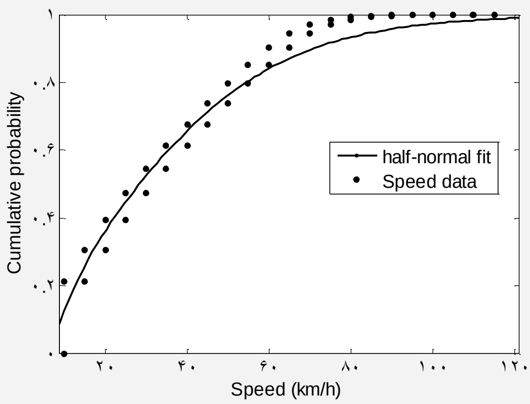


Figure 7. CDF for half-normal distribution fit

4.2. **Running simulation**

After statistical distribution has been recognized, the next step is a random number generation according to the MC procedure. In this research, Crystal Ball Pro 2000 version program has been employed to simulate the velocity of the car. (Decisioneering Inc, 2001; Goldman L. 2002) In order to achieve the cyclic pattern of the speed trend line in the simulation, an additional assumption should be defined. A section of the results is presented in Figure 8. The cycle length is about 1800sec (3150-1350) which is in total agreement with the results in section 3.1 of this paper. Appendix 3 includes the assumption and the forecast results for the A2 cycle data.

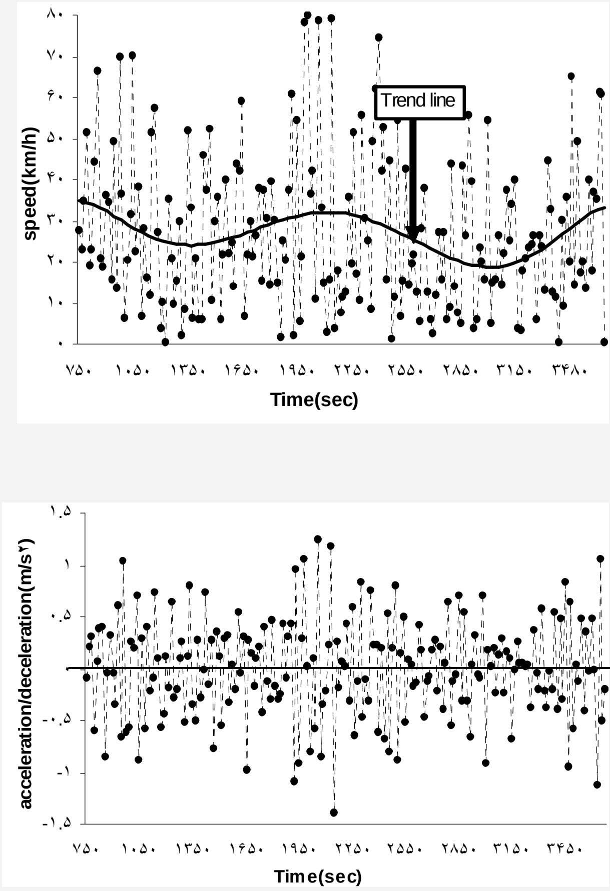


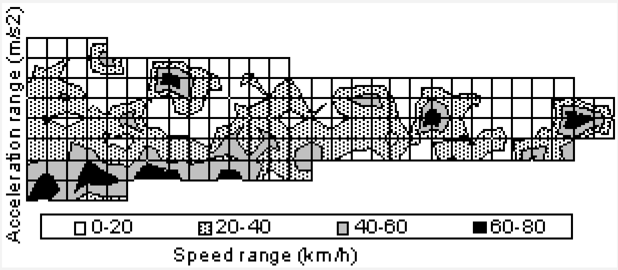
Figure 8. Up, partial simulation results for speed data, Down, acceleration/deceleration data

Table 3 summarizes the results of analysis which are valid for both A2 and A1 cycles. It is also evident from the results that in about 98% of the time the speed is below 80km/h. For acceleration of the taxi, the worst case scenario happens when the full loaded vehicle (weights 1700kg maximum) has to speed up by maximum acceleration (1.46m/s^2 from Table 3). It demands a 62.05kw~45hp well below 65hp of section 2.2. These proves the overcapacity design of the powertrain.

The joint distribution of the speed and acceleration can also be used to determine the range of speed where maximum/minimum acceleration occurs. Figure 9 shows such a graph for the data presented in Figure 8. It is remarkable that the greatest values of acceleration are belonged to low speed zone (0-20km/h) and the maximum deceleration (breaking) happens at high speed zone (60-80km/h).

Table 3. Summery of simulation results for fixed routes

Parameter	Average	Maximum	Minimum
Speed (km/h)	24.87	79.94	0
Acceleration (m/s^2)	0.37	1.45	0
Deceleration (m/s^2)	0.37	1.46	0



-1.5_-1.2	-1.2_-0.9	-0.9_-0.6	-0.6_-0.3	-0.3_0
0_0.3	0.3_0.6	0.6_0.9	0.9_1.2	1.2-1.5
Acceleration range (m/s2)				

Figure 9. Joint distribution of the speed and acceleration

For variable route service, in the absent of the cyclic pattern and due to more frequent stops, the average speed and acceleration as well as the maximum levels are less than fixed route service. The detail is not included since it was not within the scope of this research.

5. CONCLUSION

Driving cycles were developed using Monte Carlo method to verify the fitness of a passenger car for public transport services. It is shown that the speed range and acceleration resulted from driving cycles are significantly lower than the corresponding specifications for the actual powertrain of the vehicle. The main reasons can be the urban routes with heavy traffic, speed limits for public transports imposed by local authorities and frequent stop-starts especially in variable route services.

ACKNOWLEDGEMENT- Installation of GPS hardware as well as data collection and transfer are conducted by Mr M. Pourreza who is a software engineering student in Ferdowsi university of Mashhad.

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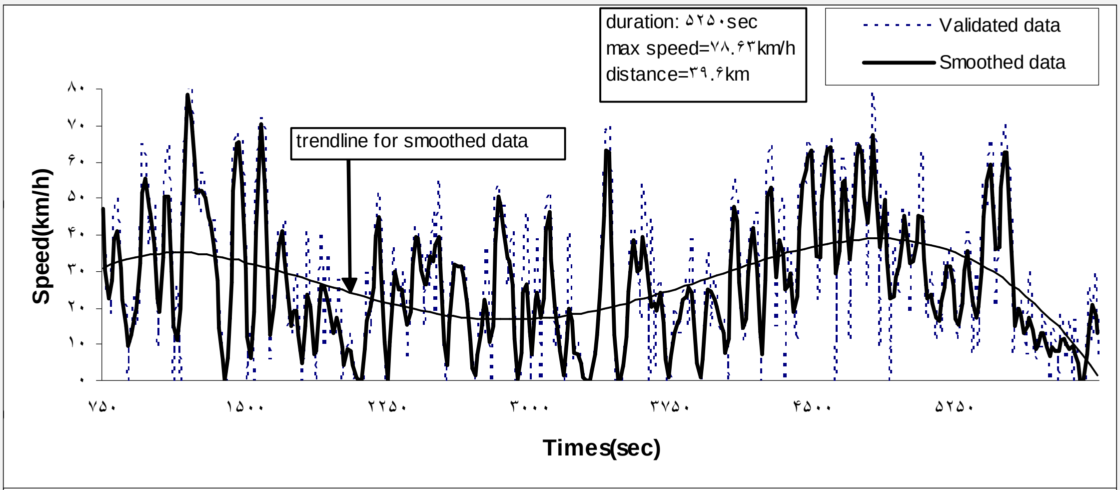
APPENDIX 1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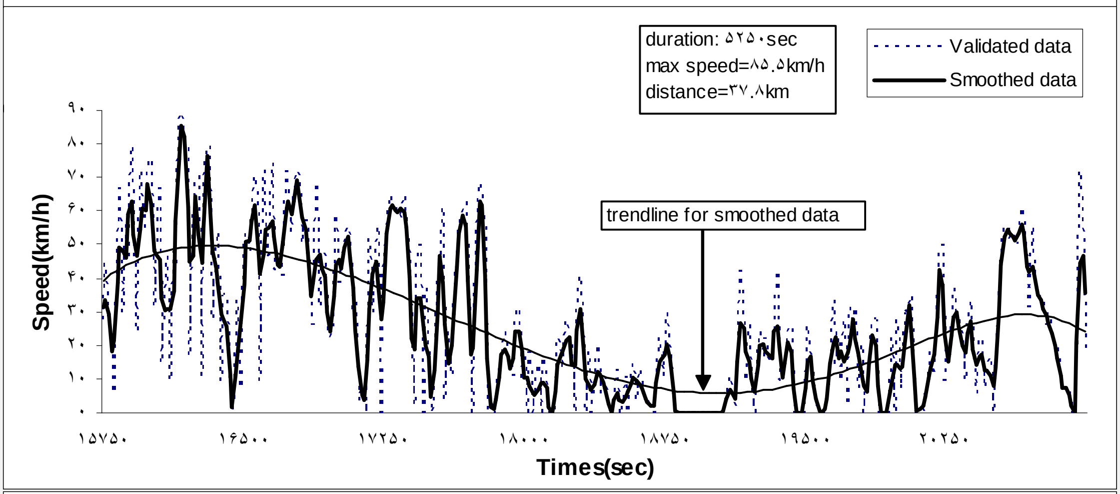
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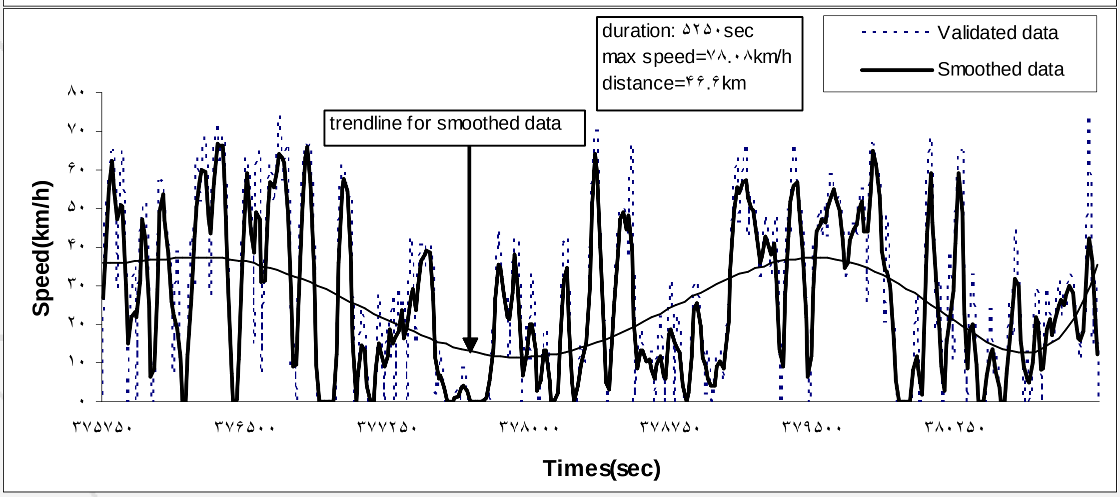
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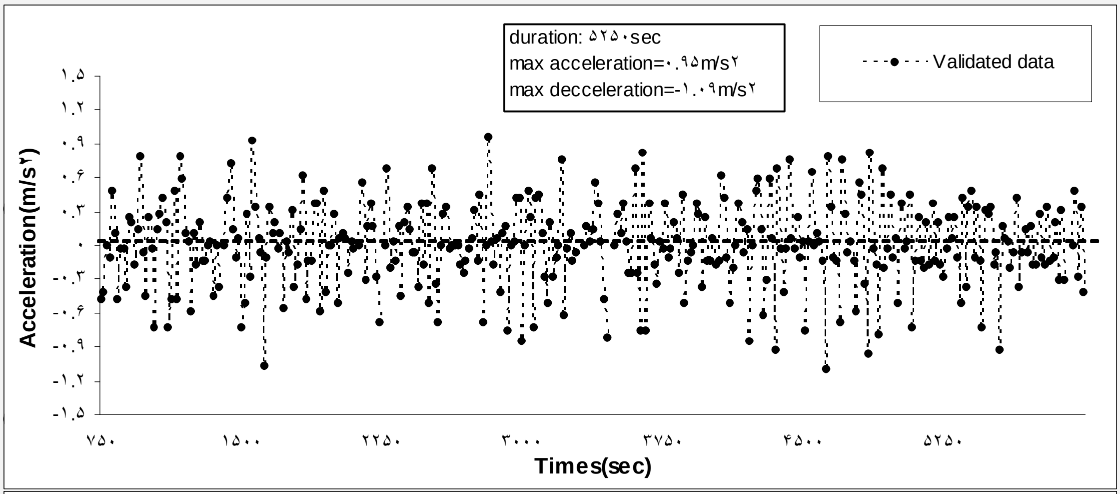
Times(sec)

APPENDIX 2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Acceleration(m/s۲)
Times(sec)
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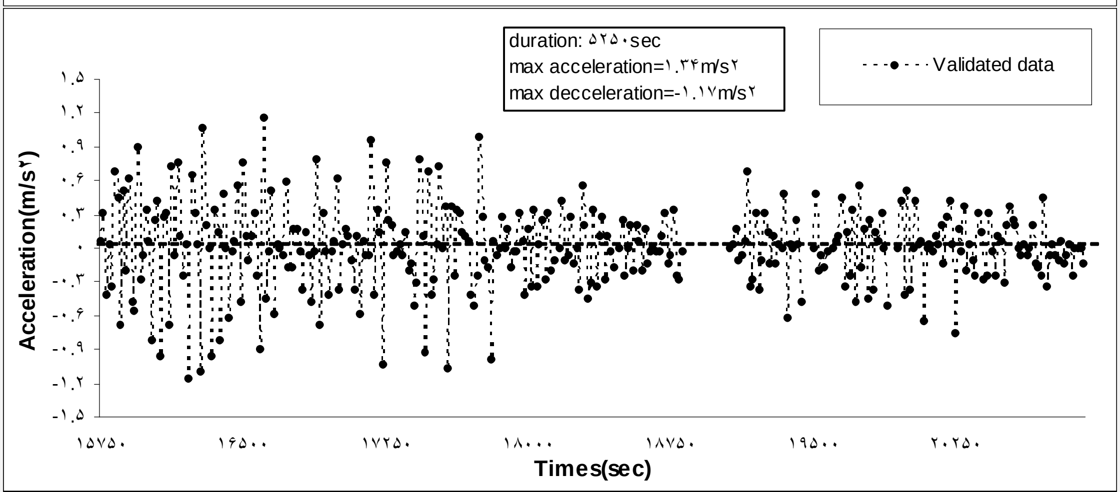
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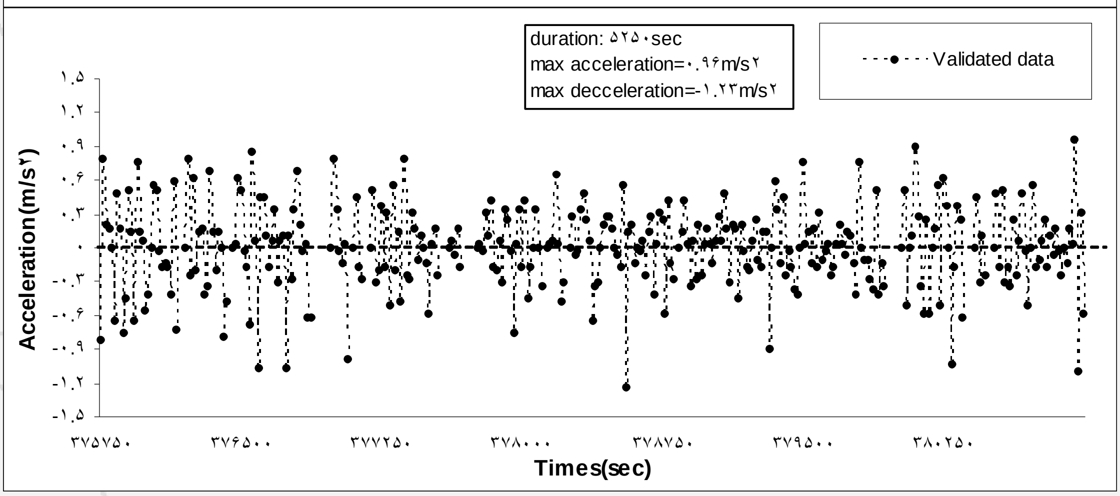
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APPENDIX 3

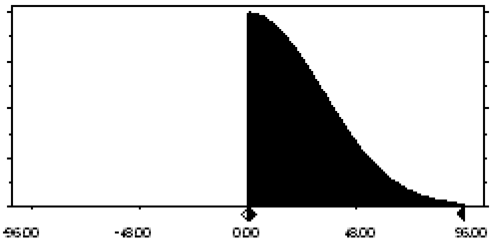
Assumptions

Assumption:

Normal distribution with parameters:

Mean	0.00
Standard Dev.	32.00

Selected range is from 0.00 to 130.00



Crystal Ball Report

Simulation started on 28/6/09 at 19:34:59

Simulation stopped on 28/6/09 at 19:35:28

Forecast:

Summery:

Display Range is from 0.05 to 75.27

Entire Range is from 0.05 to 118.94

After 1,000 Trials, the Std. Error of the Mean is 0.60

Statistics:	Value
Trials	1000
Mean	26.39
Median	27.16
Mode	---
Standard Deviation	18.97
Variance	359.90
Skewness	0.95
Kurtosis	3.82
Coeef. of Variability	0.72
Range minimum	0.05
Range maximum	118.94
Range Width	118.90
Mean Std. Error	0.6