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Procedia Technology
Procedia Technology 7 (2013) 61 – 70

Framework for Estimating Travel Time, Distance, Speed, and Street Segment Level Of Service (LOS), based on GPS Data

A. Jiménez-Meza, J. Arámburo-Lizárraga, E. de la Fuente[1,]

Ph.D in Information Technologies,
Posgrados CUCEA, Universidad de Guadalajara
Periférico Nte. 799 Mod. L305, Los Belenes, Zapopan Jalisco, México

Abstract

Street characterization might be done through its distance, travel time, average speed, flow or density. In this paper, the Level of Service (LOS) has been used as an alternate measure to characterize street segments, LOS categorizes the traffic status according to quality of service of an urban street, considering three categories: few traffic, moderate congestion and congested. The proposed framework uses three GPS-Data fields (Date-Time, Latitude, and Longitude) to estimate Travel Time, Distance and Speed at two different levels of analysis: GPS-Data traces and street segments. At segment level of analysis average speed has been used to calculate LOS scale and characterize street segments with a LOS, color and performance. As a case of study, a subset of 1012 GPS-Data traces, gathered from Beijing, China, were analyzed. This trajectory data corresponds to 90 minutes of a Taxi. The implementation of this framework showed that, using only three GPS-Data fields, traffic information about individual vehicles can be estimated and used to characterize street segments with the average speed and its corresponding LOS.

Selection and peer-review under responsibility of CIIECC 2013

Keywords: Information Technologies, Smartcities, Travel Time Estimation, GPS-Data, Instantaneous speed

1. Introduction

Mobility tracking using GPS devices has brought to the transportation engineering community a new perspective to gather vehicle information. These devices are enabled to collect Geo Positioning System traces, called GPS-Data, including device-ID, location in coordinates, time, speed and distance. This information might be saved into the device for its future analysis, it can be used on vehicle to vehicle analysis systems, or send it to a server in Real-Time for its immediate analysis, for instance it can be used to explain the vehicular dynamics of urban cities as micro and macroscopic simulations, traffic flow and travel time estimations.

Email addresses: anaj@cucea.udg.mx (A. Jiménez-Meza), jaramburo@cucea.udg.mx (J. Arámburo-Lizárraga), edfuente@gmail.com (E. de la Fuente)
URL: http://itphd.cucea.udg.mx (E. de la Fuente)
[1]Departamento de Física, CUCEI, Universidad de Guadalajara

Selection and peer-review under responsibility of CIIECC 2013
doi:10.1016/j.protcy.2013.04.008

Travel Time Estimation for an UTN might be done through street segment Travel Time Estimation, and subsequently use it to calculate travel time over a path, given by an origin to a destination point. In this context, in [1] a framework to estimate travel time over urban street segments is presented, in this work real-time and historical bus-car travel information is used, although the model shows robust travel-time estimation, the author suggests not to generalize the results unless they have been carefully examined with specific local settings. In [2] a knowledge based travel time prediction model is proposed, this model uses Real-Time and historical GPS-data gathered from mobile devices, where travel time along a path can be estimated by adding up the link travel time (historical and current) and the intersection delay. A dynamic routing Ant Based system is proposed in [3] to compute and predict travel times along road segments as well as to find the fastest routes. A method based on taxi trajectories to find the fastest route is proposed in [4], this method uses a time-dependent Landmark Graph and an algorithm to estimate travel time between two landmarks.

The main goal of this work is to propose a framework for GPS-Data traces analysis, street segments characterization with its corresponding Level of Service (LOS) and color, and their graphical representation into a map. The implementation of this framework could help to analyze individual vehicle traces, present statistics and visualize the traffic performance over the traveled route.

The main advantages of this framework compared with the aforementioned works is the calculus of travel time, distance, average speed, LOS and route visualization at two different levels: GPS-Data traces and street segments. This framework can be applied in the context of Information Technologies to collect, analyze and distribute information through an Intelligent Transportation System, for instance, the usage of smarpthones as probe vehicles to perform these operations, contributes to the development of smartcities in the dimension of smart mobility proposed in [5].

Next sections are organized as follows: section 2 gives a short introduction to the traffic flow foundations and states the importance of Travel Time Estimation and Prediction applied to Intelligent Transport Systems. Section 3 presents the steps involved in the proposed Framework for GPS-Data traces analysis, street segment characterization with a Level of Service (LOS), and their graphical representation into a map. In section 4, the results of applying the framework to a subset of 1012 GPS-Data traces, gathered from Beijing, China, are presented. And section 5 presents the conclusions and future work.

2. Traffic Flow Background

The Federal Highway Administration (FHWA), through its Revised Monograph on Traffic Flow Theory [6], presents the traffic flow theories, used to describe in a precise mathematical way the interactions between vehicles, their operators (the mobile components) and the infrastructure (the immobile component).

Traffic Flow Models are classified according its level of detail mainly into Microscopic and Macroscopic Models. As stated in [7], Microscopic Models distinguish and trace single cars and their drivers; car's position, speed and acceleration are calculated for each time step, and driver's behavior is generally described by a large set of if-then rules. According to [8], Macroscopic Models represent the traffic stream in an aggregate manner considering a low level of detail, formulating the relationships among the traffic flow characteristics, as flow-rate, density and mean speed. In this paper Macroscopic Speed-Flow models are studied.

2.1. Greenshields Model

The Greenshields Model proposed in 1935 [9] has been considered as the pioneer in the field of traffic flow descriptions. This work considers to perform tests to measure traffic flow, traffic density and speed using photographic measurement methods. In [9] a linear relationship among speed and traffic density is stated, with a flow function $q = k * v$ where q = traffic flow is measured in vehicles per hr, k= density in vehicles per km, and v= speed in km/hr. Also, the Fundamental Diagram is proposed and used to represent graphically the relationship among these traffic flow characteristics.

2.2. GPS

The next generation of modeling traffic flow data is moving towards the usage of gathered information in Real-Time from Global Positioning System (GPS) devices, which could be dedicated GPS Devices, or a GPS embedded into a smartphone. These devices might overcome the drawbacks of depending on costly or inaccessible sources of information, e.g. data from physical sensors or from video cameras placed over the roads. GPS-Data gathered in Real-Time as well as historical data could be analyzed and processed to be used on a traffic control system and once this information is ready, it might be sent back to a mobile device or a to a control system for its graphical representation. In summary, the development of an Intelligent Transportation System to collect, analyze and distribute vehicular traffic data. In [10], [2], [1], these technologies were integrated to gather and analyze information in Real-Time. In [11], the combination of Historical and Real-Time data was used to estimate and predict travel times over a traffic network. These validates that using this type of technology can help to monitor vehicular traffic status over an UTN, for instance in [10] is stated that " the penetration of cell phones in the driver population is enough to provide accurate measurements of the velocity of the traffic flow". In this context, GPS-Data can be used for Travel Time prediction in real-time, as shown in [2].

2.3. Urban Street Level of Service (LOS)

The Highway Capacity Manual 2000 [12], published by the Transportation Research Board (TRB), presents the LOS as a quantitative stratification of quality of service into six letter grade levels. They describe traffic conditions in terms of speed and travel time, volume and capacity. In terms of the mean speed of through traffic over an urban street, LOS are described in Table (1):

Table 1. Urban Street LOS categorization, used to characterize street segments based on average speed

Typical FFS	80 km/h	64 km/h	56 km/h	48 km/h			
Class	I	II	III	IV			
LOS					LOS Scale	Color	Performance
A	> 68	> 57	> 49	> 49	5	Green	Good
B	57 - 68	47 - 57	40 - 49	32 - 49	4	Green	Good
C	45 - 56	35 - 46	29 - 39	22 - 31	3	Yellow	Acceptable
D	36 - 44	27 - 34	22 - 28	16 - 21	2	Yellow	Acceptable
E	27 - 35	22 - 26	16 - 21	12 -15	1	Red	Poor
F	< 26	< 21	< 16	< 11	0	Red	Poor

FFS=mid-block free-flow speed of street
Good=Few Traffic. Acceptable=Moderate Congestion. Poor= Congested
Data converted from mph to km/h. Source: Highway Capacity Manual 2000 [12] and adapted from [13])

In the NCHRP Report 616 [13] a model is presented to calculate the LOS over urban streets, which can be expressed (approximately) in the form of a linear function of facility type and speed, as follows:

$$LOS = Integer[(0.151231 * Speed) + (0.636927 * Class) - 2.17765] \quad (1)$$

Where
LOS = HCM LOS Integer Scale (where A=5, F = 0). See Table (1)
Integer = The integer function (rounds off the value to the nearest integer value)
Speed = Mean speed of through traffic on arterial in mph
Class = Arterial Class as defined by HCM (Class I, II, III, or IV)

3. Proposed Framework

The main goal of this paper is to present a framework to estimate distance, interval time, and speed, between successive GPS-Data traces and to associate average speeds per segment to a LOS. The proposed calculus are based on three GPS-Data fields: date-time, latitude, and longitude registered during a vehicle route. It includes two different levels of analysis: GPS-Data traces and street segments. GPS-Data traces analysis provides statistics about the traveled route and allows street segment characterization with a LOS and a color, as well as, the visualization of the traffic performance over a map. Figure (1) presents the overall framework into a UML Activity Diagram.

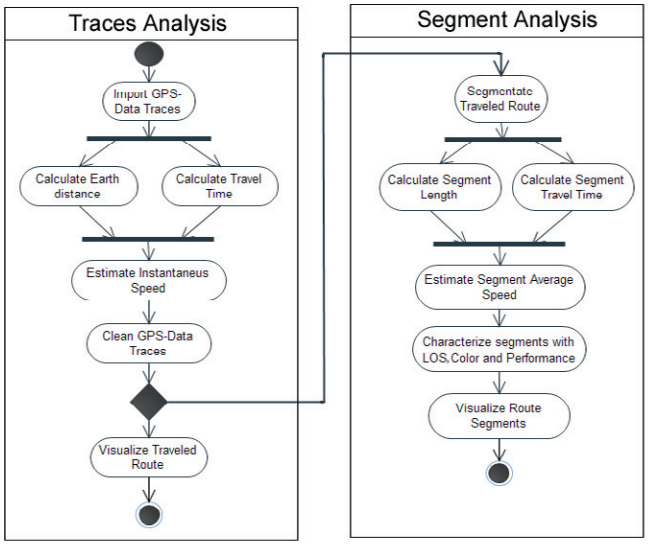

Fig. 1. Framework overview. Two levels of GPS-Data analysis: Steps 1-6 Traces Analysis, Steps 7-12 Segment Analysis

1. Import the GPS-Dataset file to a new spreadsheet file. If the data appears in only one column, separate it into columns to work with it as data fields. Set the dataset headers and change the columns in the following order: Vehicle-ID, Date-Time, Latitude, longitude. See Table (2).

Table 2. Ordered Data set with headers

Vehicle-ID	Date-Time	Latitude	Longitude
1131	02/02/2008 13:30	39.86973	116.45804

2. Calculate ground distance between the two coordinates with the following equations [14]:

Due to the earth shape, calculating accurate distance between two points requires spherical geometry and trigonometric math functions. In this framework is suggested to calculate approximate distances using simple math function, assuming that simple math equations might reduce programming and processing computation, but might produce accuracy errors. If more accuracy is needed, the reader is encouraged to use the Great Circle Distance Formula proposed in the Meridian World Data web page [14].

To calculate ground distance from one coordinate to the next one, it is necessary to calculate the distance between consecutive latitudes and longitudes. In geometric words, the cathetus A, cathetus B, and hypotenuse d, which correspond to the distance between 2 latitudes, longitudes and finally the distance among two GPS-Data traces, as follows:

$$A = 69.1 * (Lat2 - Lat1), \tag{2}$$

where $Lat1$ is the latitude of the Coordinate-1 and $Lat2$ is the latitude of Coordinate-2.

$$B = 69.1 * (Lon2 - Lon1) * COS(Lat1/57.3), \tag{3}$$

where $Lon1$ is the longitude of the Coordinate-1 and $Lon2$ is the longitude of the Coordinate-2.

Constants 69.1 and 57.3 are used to convert the coordinate degrees into ground distance in miles, where one degree of latitude is equal to 69.1 miles, and one degree of longitude is equal to 53 miles [14].

$$d = \sqrt[2]{A^2 + B^2} * 1609.344, \tag{4}$$

where d is the groung distance given in meters, constant 1609.344 is used to convert miles into meters.

3. Calculate the instantaneus travel time in seconds [15] between two successive GPS coordinates using,

$$t = (ct2 - ct1) * 86400, \tag{5}$$

where t is the travel time in seconds between the two GPS coordinates and $ct1$ and $ct2$ are the registered time in coordinate-1 and coordinate-2 respectively. The interval time between GPS-Data traces is given in seconds in the format of 24 hours, due to this reason the obtained value should be multiplied by 86400 (24 hours in seconds) to obtain the instantaneus travel time between two successive coordinates.

4. Calculate instantaneus speed [15] between two GPS coordinates in km/h using,

$$v = \frac{d}{t} * 3.6, \tag{6}$$

where v is the instantaneus speed calculated among 2 consecutive GPS-Coordinates in km/h. As distance d was calculated in meters and time t in seconds. To convert m/s into km/h the instantaneous speed is multiplied by 3.6 constant.

5. Clean GPS-Data traces. It was found in [16] that GPS-Data frequently includes errors, specially in urban areas where satellite coverage may be poor due to high buildings and tunnels, as well as to atmosphere conditions, measurement noise and others, then it is necessary to clean traces before its analysis, eliminating those records with instantaneus speeds above 80 km/h.

6. Route Visualization. Invert Latitude and Longitude columns, to have Longitude as the x-axes and Latitude as y-axes in the Cartesian system. Select Longitude and Latitude columns and use a scatter plot to display the GPS-Data route followed by the vehicle. This route could be used as an upper layer to be visualized over the corresponding map obtained from Google Maps or Open Street Maps. To obtain the corresponding map take the first and the last GPS-Data traces used in the analyzed data-set, then select the area and place it as the background layer of the scatter plot, adjust the scatter plot size to exactly fit the route into the map.

As an alternate form to graphically visualize the route, select latitude and longitude columns (with its corresponding header latitude and longitude), paste them into a new spreadsheet, and save the route file using XML, CSV, or XLS format. Then go to the GPSVisualizer web page [1], follow the instructions given in the "Get started now:" box, "Upload a GPS file", "Choose an output format" and click "Go". This will display the traveled route over the corresponding map.

[1]http:www.gpsvisualizer.com

7. Street segmentation. Once the GPS-Data traces analysis has been done, the next step is to identify the street segments using a map matching technique, which associates GPS-Data traces with the topological city segments. Another technique is to divide the route into segments defined by a specific length, for instance 500m, 1 km or 1 mile and identify them with a unique number. Assign this number to each of the corresponding GPS-Data traces.

8. Calculate Segment length L_{Ξ} ,

$$L_{\Xi} = \sum_{i=1}^{n} d, \tag{7}$$

where, n last trace of the segment, d is the distance among two consecutive GPS-Data traces.

9. Calculate Segment Travel Time T_{Ξ} , [15],

$$T_{\Xi} = \sum_{i=1}^{n} t, \tag{8}$$

where t is the travel time among two consecutive GPS-Data traces.

10. Calculate Segment Average Speed V_{Ξ}, [15] by applying Equation (6) to segments. Use segment length from Equation (7) and Travel Time from Equation (8) as follows:

$$V_{\Xi} = \frac{L_{\Xi}}{T_{\Xi}} * 3.6 \tag{9}$$

11. Segment characterization. Use Table (1), Equation (1) and segment average street from Equation (9) to calculate the LOS scale and assign a LOS per segment, status color and performance according to the LOS scale.

12. Use a spreadsheet to separate the traces per segment into a different file. Place the GPS-Data traces corresponding to each segment into a separate sheet, but in the same file. Be sure to write the latitude, longitude and color headers, write the street segment color, only to one row. Open the GPSVisualizer webpage and use the generated file to graphically visualize the characterized segments.

4. Case of Study

To evaluate the proposed framework, a subset of a public GPS-Data set from the Microsoft Research Group [2] was used. This information was gathered from 10,300 GPS enabled taxis during 8 days in Beijing, China [4], [17]. The analyzed subset was taken from the first 1012 entries of the TAXI-ID 1131 gathered on February 2nd., 2008. These traces correspond to a trajectory of 90 minutes, from 1:30 PM to 3:00 PM. The data set is provided in ".txt" files, integrating 4 data fields: TAXI-ID, Date and time, Longitude, and Latitude in CSV format (Comma Sparated Values). See Table (3).

Table 3. Traces from the GPS-Dataset in CSV format, used as the main source of input data

1131.txt
1131,2008-02-02 13:30:54,116.45828,39.8697
1131,2008-02-02 13:30:59,116.45847,39.86964
1131,2008-02-02 13:31:04,116.45852,39.86954
1131,2008-02-02 13:31:09,116.45851,39.86955

[2] http://research.microsoft.com/apps/pubs/?id=152883

4.1. Traces Analysis

Using this information, and applying the proposed framework distance, interval time, and speed between two contiguous GPS-Data traces were estimated. Subsequently, with these results, the traveled distance and the average speed of the taxi 1131, from 1:30PM to 3:00PM, was obtained. Table 4 shows partial results of applying steps 1-5 of the proposed framework. Once steps 1-5 have been followed the results over the traveled route can be presented. Table 5 shows the overall results obtained from the analysis of the 1012 records, of the TAXI-ID 1131: To graphically visualize the taxi route, GPS-Data traces (latitude and longitude) were analyzed with a scatter plot, and this plot was contrasted with the corresponding Google Map picture, the same file out put was used to visualize the route in the GPS Visualizer web page. Figure (2) represents the analyzed route used in the framework evaluation, it contains 2 graphical layers, the background taken from the OpenStreetMap [3] web page and the upper layer generated with the scatter plot in the spreadsheet [4].

Table 4. Partial results of successive GPS-Data traces analysis

Step 2	Step 2 (m)	Step 2 (m)	Step 3 (sec)	Step 4 (km/h)
A Cat-Lat (m)	B Cat-Lon (m)	Distance (m)	Time (sec)	Speed (km/h)
-0.002073	0.01272	20.74	5	15
-0.004146	0.01007	17.53	5	13
-0.00691	0.00265	11.91	5	9
0.000691	-0.00053	1.40	5	1

Table 5. Overall results. Taxi-ID 1131. 02-Feb-2008

Starting Time	Ending Time	Travel Time	Distance	Average Speed
1:30PM	3:00PM	90min	29.07km	25k/h

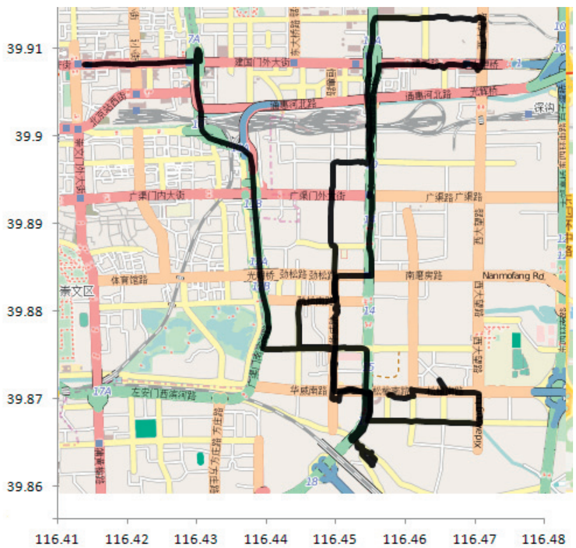

Fig. 2. Two-Layer output: OpenStreet Map and Excel Scatter Plot for GPS-Data traces visualization

[3]http://www.openstreetmap.org/
[4]Microsoft Excel

4.2. *Segment Analysis*

Once 1012 GPS-Data traces were analyzed, 49 street segments were identified according to the city topology of Beiging, Ching. Steps 7 through 11 were followed to estimate: L_Ξ , T_Ξ, V_Ξ, LOS Scale, LOS, Color, and Performance. Final results of the street segment analysis and characterization are presented in Appendix A. Finally, according to Step 12, Figure (3) shows the route performance according to the estimated LOS and color.

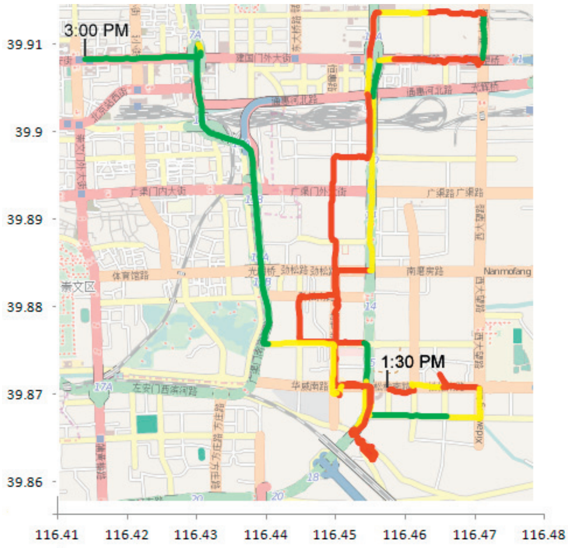

Fig. 3. GPS Visualizer output. Route performance according to its LOS and color association

Figure (4) shows a plot of the average speed registered per segment along the 90 minutes route.

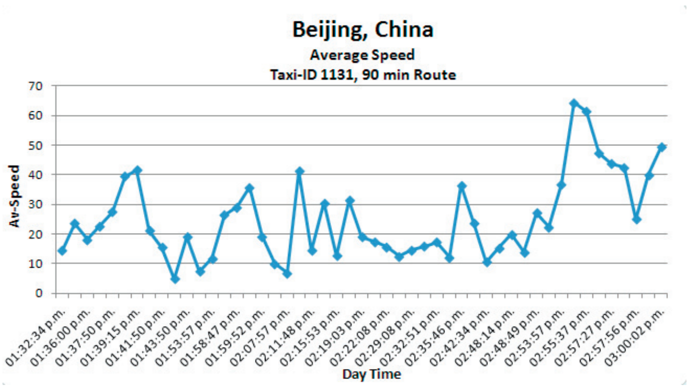

Fig. 4. Graph of average speeds over the time along the GPS-Data route (49 segments)

5. Conclusions

The application of this framework showed that using only 3 GPS-Data fields: latitude, longitude and date-time is possible to find information about individual vehicles, including travel time, distance, and

instantaneous speed, as well as to estimate travel time, distance and average speed between two random points within the route. This framework can be a useful guide to those people interested in the analysis and visualization of GPS-Data gathered from moving vehicles. These estimated data (time, distance and instantaneous speed) might be used to accurately analyze GPS-Data, e.g. instantaneous speed might be used to clean GPS-Data traces, which could be wrong recorded by the GPS devices. Once individual traces have been analyzed, the obtained information might be used to estimate traveled distances, average speeds, and travel time over street segments. These values could be used to characterize urban street segments over a Traffic Network System (TNS)and subsequently use an algorithm to find the best route according to the value (travel time, distance, or speed) that obtains the best result. The average speed might be associated to the quality of service or the Level of Service (LOS) of an urban street network.
As future work we are proposing a congestion Index to characterize street segments for estimating Travel Time and Delay Time over segments, this value might be used to subsequently find the shortest route to travel from one point to another.

6. Acknowledgments

A.J.M. wishes to thank the University of Guadalajara and CONACYT with grant No. 35022, for financing this project and offer the opportunity of being part of this student community. Special thanks to my advisors, J.A.L. and E.de la F., for their worthy help in every moment of this work development.

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Appendix A. Segment Analysis and Characterization results

Table A.6. Segment Analysis and Characterization results used as input values to visualize the route performance

Step 7		Step 8	Step 9	Step 10		Step 11	Step 11	Step 11	Step 11
SegID	Date-Time	Seg Length	Travel Time	AV Speed	Class	LOS Scale	LOS	Color	Performance
1	01:32:34 p.m.	405	105.00	14	2	1	E	Red	Poor
2	01:33:39 p.m.	427	1.08	24	2	2	D	Yellow	Acceptable
3	01:36:00 p.m.	818	141.00	18	2	1	E	Red	Poor
4	01:36:45 p.m.	285	45.00	23	2	2	D	Yellow	Acceptable
5	01:37:50 p.m.	497	65.00	28	2	3	C	Yellow	Acceptable
6	01:38:30 p.m.	439	40.00	40	2	5	A	Green	Good
7	01:39:15 p.m.	532	45.00	42	2	5	A	Green	Good
8	01:39:45 p.m.	179	30.00	21	2	2	D	Yellow	Acceptable
9	01:41:50 p.m.	426	95.00	16	2	1	E	Red	Poor
10	01:42:15 p.m.	34	25.00	5	2	0	F	Red	Poor
11	01:43:50 p.m.	523	105.00	19	2	1	E	Red	Poor
12	01:51:25 p.m.	1018	455.00	7	2	0	F	Red	Poor
13	01:53:57 p.m.	475	152.00	12	2	0	F	Red	Poor
14	01:56:02 p.m.	995	125.00	27	2	3	C	Yellow	Acceptable
15	01:58:47 p.m.	1291	165.00	29	2	3	C	Yellow	Acceptable
16	01:59:32 p.m.	462	45.00	36	2	4	B	Green	Good
17	01:59:52 p.m.	191	20.00	19	2	2	D	Yellow	Acceptable
18	02:05:12 p.m.	1099	320.00	10	2	0	F	Red	Poor
19	02:07:57 p.m.	296	165.00	7	2	0	F	Red	Poor
20	02:08:47 p.m.	552	50.00	41	2	5	A	Green	Good
21	02:11:48 p.m.	796	181.00	15	2	1	E	Red	Poor
22	02:12:58 p.m.	593	70.00	30	2	3	C	Yellow	Acceptable
23	02:15:53 p.m.	657	175.00	13	2	1	E	Red	Poor
24	02:16:43 p.m.	431	50.00	31	2	3	C	Yellow	Acceptable
25	02:19:03 p.m.	748	140.00	19	2	1	E	Red	Poor
26	02:20:28 p.m.	486	85.00	17	2	1	E	Red	Poor
27	02:22:08 p.m.	456	100.00	16	2	1	E	Red	Poor
28	02:26:33 p.m.	1036	265.00	13	2	0	F	Red	Poor
29	02:29:08 p.m.	683	155.00	15	2	1	E	Red	Poor
30	02:31:13 p.m.	594	125.00	16	2	1	E	Red	Poor
31	02:32:51 p.m.	444	98.00	17	2	1	E	Red	Poor
32	02:34:56 p.m.	434	125.00	12	2	0	F	Red	Poor
33	02:35:46 p.m.	507	50.00	37	2	4	B	Green	Good
34	02:38:46 p.m.	638	180.00	24	2	2	D	Yellow	Acceptable
35	02:42:34 p.m.	671	228.00	11	2	0	F	Red	Poor
36	02:48:04 p.m.	1461	330.00	15	2	1	E	Red	Poor
37	02:48:14 p.m.	111	10.00	20	2	2	D	Yellow	Acceptable
38	02:48:29 p.m.	59	15.00	14	2	1	E	Red	Poor
39	02:48:49 p.m.	151	20.00	27	2	3	C	Yellow	Acceptable
40	02:52:32 p.m.	1361	223.00	22	2	2	D	Yellow	Acceptable
41	02:53:57 p.m.	935	85.00	37	2	4	B	Green	Good
42	02:54:57 p.m.	1039	60.00	64	2	5	A	Green	Good
43	02:55:37 p.m.	661	40.00	61	2	5	A	Green	Good
44	02:56:22 p.m.	616	45.00	47	2	5	A	Green	Good
45	02:57:27 p.m.	775	65.00	44	2	5	A	Green	Good
46	02:57:42 p.m.	185	15.00	42	2	5	A	Green	Good
47	02:57:56 p.m.	127	14.00	25	2	2	D	Yellow	Acceptable
48	02:59:07 p.m.	732	71.00	40	2	5	A	Green	Good
49	03:00:02 p.m.	754	55.00	49	2	5	A	Green	Good