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SHOULD WE CHANGE THE RULES FOR TRIP IDENTIFICATION FOR GPS TRAVEL RECORDS?

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ABSTRACT

GPS data processing usually consists of trip identification (TI), mode detection and purpose imputation. Given that most research needs to process millions of data points, it is always debatable what the optimal interval is to record data. In practice, most research uses one second as the interval, whilst some researchers use 3 seconds, 5 seconds, or an even longer interval to record data. Also, it is usually suggested that 120 seconds of dwell time would be a reasonable criterion to identify a stop. However, some activities, such as pickup/drop-off, may have a shorter duration. This paper investigates both issues in depth. This paper also discusses the trade-offs of choosing different options, suggests the relatively better option and the ways to cope with the trade-offs.

1 BACKGROUND

GPS has been used for travel surveys for more than a decade. Most GPS surveys record GPS points every second ((Stopher et al., 2008; Bohte and Maat, 2009) while there are also several surveys (Feng et al., 2011; Mohammadian et al., 2011) using three seconds or an even longer time as an interval to record the GPS data. According to Mokhtarian and Chen (2004), the travel time budget for a person is 1.1 h-1.3 h per day, so the number of GPS points for that person is about 4000 per day if the time interval to record GPS data is one second. Thus, there will be about 3 million GPS points for a sample of one hundred persons who travel for a week, which would constitute a large dataset. Therefore, a suitable and efficient method to process the data is essential.

One issue of processing GPS data is the processing time. Because different applications have used different time intervals to record the data and those intervals would influence the processing time, it is worthwhile testing and comparing different time intervals to see what influences each option would have on the final processing results. This paper tests four options —1 second, 3 seconds, 5 seconds, and 10 seconds—to show the different impacts of each option.

Another issue in processing is to identify the stops/activities, because the accuracy of identifying the stops directly determines the accuracy of identifying the number of trips. Current processing typically uses 120 seconds (Wolf, 2000; Stopher et al., 2008) as a rule to split the journey into trips because the traffic signal cycle should always be less than 120 seconds according to the Highway Capacity Manual (HCM, 2010) and the signal light stops should not be regarded as trip ends. However, this arbitrary rule has a problem to find any stop less than 120 seconds, which some activities, e.g., pick-up/drop off or buy a snack at a convenience store, would usually take. Also, traffic congestion would possibly lead to more than a 120-second stop for vehicles. On the other hand, if the threshold of the minimum break time is reduced, there may be more stops identified than are actually correct. This paper also tests different options for the minimum break time setting to show which one might be the optimal option.

2 DATA COLLECTION

In this study, two devices, GPS and SenseCam, were used for data collection. GPS units were provided by the Institute of Transport and Logistics Studies at the University of Sydney Business School, and Microsoft SenseCams were provided by the British Heart Foundation Health Promotion Research Group at the University of Oxford. The GPS logger was set to use a one-second interval to record data.

SenseCam is a passive digital camera that contains a number of different electronic sensors. Certain changes in sensor readings can be used to trigger a photograph to be taken automatically. If nothing changes, it takes time-stamped photos every 50 seconds. Overall, it can capture images approximately every 20 seconds throughout the day and can take approximately 3000 photos per day (Hodges et al., 2006; Kelly et al., 2011). As Shen and Stopher (2013) suggested, the SenseCam camera can help to obtain ground truth, which was used for the testing in this study to see the accuracy of identification of each option. Ground truth is usually difficult to obtain by traditional survey methods. While earlier studies used a combination of GPS records and self-reported results as ground truth, which is also not correct, the most popular recent method to obtain ground truth is conducting prompted recall (PR) surveys (Bachu et al. 2001; Greaves et al., 2010), in which respondents are assisted to recall their actual travel by receiving GPS-generated maps of where and when they travelled. However, PR results are still far from ground truth due again to self-report errors, similar to those in conventional surveys (Bohte and Maat, 2009). Therefore, the new device, SenseCam provides a great opportunity for transport researchers to pursue ground truth. The reasons why ground truth is so important for current research are that: it can show all the trips that people made exactly; it can validate GPS data processing results (i.e., accuracy of processing work); and it can be used for developing a learning system for GPS data processing.

We recruited 12 volunteers in Oxford, UK and 7 volunteers in Sydney, Australia, and they were asked to carry both SenseCam cameras and GPS units with them for three or five days (volunteers in the UK carried two devices for three days and those in Australia carried the devices for five days). These are GPS and SenseCam only surveys, in which participants were not required to complete travel diaries. Participants were asked to use both devices all the time except when the devices were charging. All modes and activities (SenseCam can be paused to use due to privacy reasons) were included.

3 METHODOLOGY

The G-TO-MAP software (Stopher et al., 2008) was used for GPS data processing to identify trips. It was initially designed for processing one-second GPS data with a setting of 2 minutes (120 seconds) as a minimum break time. The data collected in this study, which were recorded every second, were processed by the software first. Missing GPS data and GPS signal noise are the main issues that GPS surveys are subject to. There are several causes for missing GPS data. The cold start is one of the principal causes, which usually occurs at the beginning of each day or when the GPS device switches from “sleep mode” to “working mode”. Travelling in urban canyons also could impact the reception of GPS signals. Also, even though the participants are always requested to charge the device every day, some may forget to do so, which could cause the issue of running out of battery at the end of a day. Apart from that, participants also might forget to take the devices with them. Signal noise, the other issue, will lead to spurious trips. Insufficient satellites and travelling in urban canyons or in tunnels are the main reasons causing signal noise. Also, there might be some random errors by satellite or receiver issues, atmospheric and ionospheric disturbances, multi-path signal reflection or signal blocking (Schüssler and Axhausen, 2009). A manual map editing was undertaken to identify the spurious trips (a sequence of points generated by a stationary GPS device that have been incorrectly identified as a trip) based on GPS-generated maps. Map editing is a manual step that is undertaken at ITLS about two-thirds of the way through the processing of the GPS data into trips (trip identification). At that point, when the records have been split into what are thought to be trips by the software, a map is produced for each person-day of data, with each trip shown in a different colour, and each of the recorded data points comprising a GIS layer. This allows a person to examine the map on a computer and, by moving the cursor onto any point, display the data stream for that point from the GPS recording. Even with deleting some invalid data based on the rules suggested by Stopher et al. (2008), some spurious trips may still be recorded by GPS units and shown in maps due to signal noise. From the map, those trips, which in fact do not exist, are usually shown as people travelling through multiple buildings without any stops. An in-depth investigation was also undertaken on a case-by-case basis to check the trips that were initially identified by G-TO-MAP.

3.1 Test of Time Interval for Recording GPS Data

The purpose of this test is to see if using a longer time interval can generate similar or even better results of trip identification than the one-second interval option. It can save a great amount of time for the processing and also save storage space for the GPS data. The intervals of 3 seconds, 5 seconds, and 10 seconds were tested, by dropping out every 2, every 4, or every 9 data points, respectively. Because the data collected for this research were recorded every second, it could be easily converted to an every 3/5/10 seconds dataset by resampling the data.

It could be expected that with the increase of the time interval and decrease of the GPS records, the number of trips and the number of stops that were identified by the software would be different between each option. Some trade-offs would exist, because using longer time intervals may lose several short distance trips due to insufficient points, but it may also add several low-speed trips because those trips sometimes look like “clouds” and the longer time intervals would cause sufficient points to be dropped that it would no longer look like a cloud of points. Correct GPS positions are calculated by at least four satellites, and the positioning accuracy of GPS receivers under ideal conditions lies between five and ten metres (Schüssler and Axhausen, 2009). As a result, even if there is no movement, there might be several metres’ difference between one GPS position and the position one second earlier. This would normally cause a “cloud” issue, where those points would look like “clouds”, but people, in fact did not move. The automated processing would regard those clouds as spurious trips and delete them. However, by changing the time interval for recording GPS data, automated processing would mistakenly delete some real trips because they would look like “clouds” due to insufficient points. The following are the consequences that changing the interval would lead to, together with the reasons why those consequences would occur. Each consequence is investigated in detail, case by case, in this study.

Consequences of changing the interval of recording data:

- Add a new real trip

These new real trips usually have low speeds, and are mistakenly deleted as spurious trips by the software because the points shown on the map look like clouds. With fewer points recorded in the dataset, the distance between each point becomes larger, and some “clouds” would become a curve or a straight line so that the software would identify those as real trips.

- Add a new spurious trip

On the other hand, the same effect as the first one could result in the software identifying a trip where there is not a trip, again because deleting points from the “cloud” makes the cloud look more like an actual trip.

- Add a new spurious stop by mistakenly splitting a trip

A larger time interval may have the risk of not recording some essential GPS points which record critical information (e.g., speed change) when the mode is changed. For example, if a person is travelling on a congested road by car, one-second data will record the speed every second, which would show some higher speed values when the car is moving. However, in the 10-second dataset, the chances are that only low-speed values (due to congestion) are recorded, and some high-speed values (when the car is moving) may not be recorded due to the larger time interval. In this case, it might be regarded as a mode change because the person may travel from a free-flow road to this congested road, and the GPS records would show that the speed/average speed of the records changed dramatically from high values to low values. As a result, a "spurious" stop may be added mistakenly.

- Add a new real stop

Because the minimum break time is set as 120 seconds for this test, a stop time of less than 120 seconds would not be detected. Increasing the time interval of recording data could increase the apparent stop time, which would add some real stops that are missed by the 120-second rule (for example, if in 5-second data, the last point recorded before a stop was 5 seconds before the stop and the first point after the stop was recorded 5 seconds after travel resumed, then a 110-second stop would appear to be 120 seconds). Also, there might be some spurious points, which look like part of a trip in one-second data, because there are some continuous movements between those points, but the spurious points are actually caused by a stop. In the dataset that has the longer time interval, there would be fewer points and the pattern of those reduced points would not be like a continuous line, so those spurious points would be deleted, which results in adding a real stop.

- Mistakenly deleting a real trip

A real trip could also mistakenly be deleted because a real trip could be regarded as a spurious trip due to fewer points when a longer time interval is applied. With fewer points, the route of a trip might be not clearly shown, and the trip would look like a spurious trip. Either automated processing or a manual map editing process would mistakenly delete the trip.

- Correctly delete a spurious trip

Some spurious trips may be regarded as real trips by G-TO-MAP because there are some continuous movements between those points. With fewer points, the distances between GPS points are increased. As a result, it would show some trips (regarded as real trips in one-second data) as spurious trips which then would be deleted by either G-TO-MAP or the map editing process.

- Fail to split a trip which was correctly split in the base option

There might be insufficient points to identify a mode change when a longer time interval is chosen to record GPS data, especially at the beginning or end of a trip when the travel mode switches between walk and car, for example.

3.2 Test of a Threshold of Dwell Time

The purpose of this test is to reduce the number of trips that should be split but failed to be split by the software, because 120 seconds could be too long as a threshold, resulting in failure to identify a stop that is less than 120 seconds. This study tested several shorter options, which are 15, 30, 45, 60, 75 and 90 seconds. By re-running the GPS trip identification procedure with a different threshold of dwell time, six new results were generated. Comparing with the result that is based on the 120-second rule, the number of increased stops can be counted for each option.

The next step is to examine those added stops to see whether they are real stops or spurious stops, because a threshold of dwell time which is less than 120 seconds may detect more real stops which are not found by the 120-second rule, but could also create more spurious stops. There are three types of spurious stops: a stop due to traffic (i.e., congested road), a stop at an intersection (e.g., waiting for traffic signals), and a stop at a bus stop/train station for boarding and alighting of other passengers. To undertake this in-depth comparison, SenseCam photos were used to provide an opportunity to make a visual check.

4 RESULTS

After the initial GPS trip identification, the number of trips from the Sydney data, based on a base option (i.e., applying the 120-second rule with one-second data) without any manual map editing, is 219, including the trips not split by the software and spurious trips. The number of trips from the Oxford data is 244. The definition of a trip in this study refers to a segment, i.e., one mode for each trip/segment. For example, a person commuting to work may walk from home to the car park, then drive from the car park to another car park near his/her work place, and then walk to his/her work place, which include three trips/segments. With the simplified map-editing procedure, which only focuses on the investigation of spurious trips, 12.8% (28 out of 219) and 14.3% of trips (35 out of 244) were found to be spurious trips, respectively for the Sydney data and the Oxford data. Also, by comparing with the ground truth, it was found that some trips were not split by the software, and some were missed from the GPS processing result. The total trips that respondents actually made (i.e., ground truth) are 259 and 285 for the Sydney and the Oxford data, respectively. Tables 4.1 shows the result of the base option for both datasets.

TABLE 4.1 Result of Base Option (Sydney Data)

Trip type	Number of trips (Sydney)	Number of trips (Oxford)
Real trips	158	145
Trips not split	33	54
Spurious trips	28	35
Missing trips	68	86
Total (Base Option)	219	244
Total (Ground Truth)	259	285

4.1 Results of Comparison between Different GPS Recording Intervals

Three-second, 5-second, and 10-second options were also run by G-TO-MAP. As discussed in Section 3.1, seven consequences may occur when the interval of recording the data is changed. Table 4.2shows the results for each option for the Sydney data. Due to the increase in the time interval for recording data, some real trips were regarded as spurious trips and mistakenly deleted. In addition, some trips were mistakenly joined. As a result of these two reasons, for the Sydney data with 158 trips recorded from the 1-second data, 153 real trips were found for the 3-second option, while 154 and 142 real trips were found for the 5-second and 10-second options, respectively. New real trips were also identified by the longer time interval options. In terms of the 5-second option, it identified 15 new real trips, which is about 6% (15 out of 259) of total trips. Thus, the total numbers of real trips for each option are respectively 154, 169 and 155.

Because of this trade-off, taking the Sydney data as an example, compared with 158 trips from the base option, the 3-second and 10-second options have less real trips overall, and the 5-second option identified more real trips. At the same time, some spurious trips were deleted from the 28 spurious trips in the base option; however, new spurious trips were also generated due to an insufficient number of data points. The 5-second option mistakenly regarded the most spurious trips (i.e., 20) as real trips. Although the 3-second option identified the least new real trips (only one), it also generated the least spurious trips. The total numbers of spurious trips for the 3-second, 5-second, and 10-second options are 25, 40, and 33 respectively. The total numbers of trips that were not split are similar between each option. A similar result is shown in Table 4.3 for the Oxford data.

TABLE 4.2 Comparison of Processing Results between Different Options (Sydney Data)

Consequence	The Base Option Number of trips/stops	3-Second Option Number of trips/stops	5-Second Option Number of trips/stops	10-Second Option Number of trips/stops
Real trips (also recorded in the Base Option)	158	153	154	142
Spurious trips (also recorded in the Base Option)	28	21	20	17
New real trips	N/A	1	15	13
New spurious trips	N/A	4	20	16
New spurious stops	N/A	2	2	2
New real stops	N/A	1	2	3
Delete real trips	N/A	4	2	7
Delete spurious trips	N/A	7	8	11
Fail to split trips	N/A	1	2	9
Total real trips	158	154	169	155
Total spurious trips	28	25	40	33
Total trips not split	33	34	33	32

N/A= not applicable

TABLE 4.3 Comparison of Processing Results between Different Options (Oxford Data)

Consequence	The Base Option Number of trips/stops	3-Second Option Number of trips/stops	5-Second Option Number of trips/stops	10-Second Option Number of trips/stops
Real trips (also recorded in the Base Option)	145	138	140	140
Spurious trips (also recorded in the Base Option)	35	27	29	26
New real trips	N/A	2	10	9
New spurious trips	N/A	7	35	28
New spurious stops	N/A	4	4	5
New real stops	N/A	1	2	3
Delete real trips	N/A	5	1	2
Delete spurious trips	N/A	8	6	8
Fail to split trips	N/A	2	4	3
Total real trips	145	140	150	149
Total spurious trips	35	34	64	55
Total trips not split	54	57	56	56

N/A= not applicable

Figures 4.1 and 4.2 show the overall change of the number of real trips and spurious trips. Even though the 5-second option has the most real trips, it is still necessary to be careful to draw a conclusion that it is the optimal option because of the large number of spurious trips. In this study the 5-second option can identify more real trips than the other three options overall (16, 25 and 15 more real trips than the base option, 3-second option and 10-second option, respectively), and generate more spurious trips (41, 45 and 16 more spurious trips than the other three options, respectively). The cost between adding real trips and deleting spurious trips needs to be estimated. Based on the experience of map editing work, manually adding a real trip is much more expensive than deleting a spurious trip. Specifically, it would take at least 2 minutes to add a new trip; by contrast, removing a spurious trip would only take 30 seconds. The ratios of additional new real trips to additional new spurious trips over the other three options are respectively 16/41, 25/45 and 15/16. All of them are more than the ratio of the cost of adding a real trip to the cost of deleting a spurious trip (i.e., 0.25).

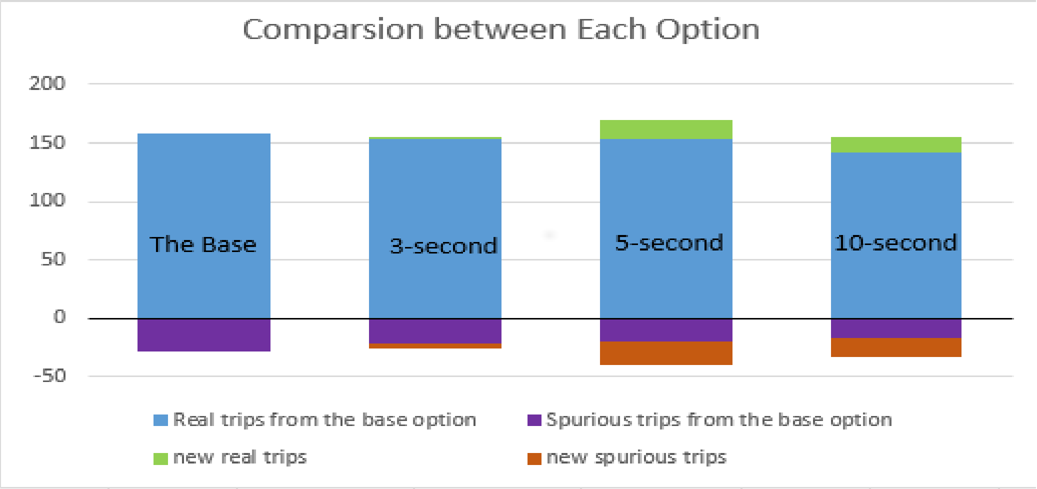

FIGURE 4.1 Overall Change in Total Number of Real and Spurious Trips for Each Option (Sydney Data)

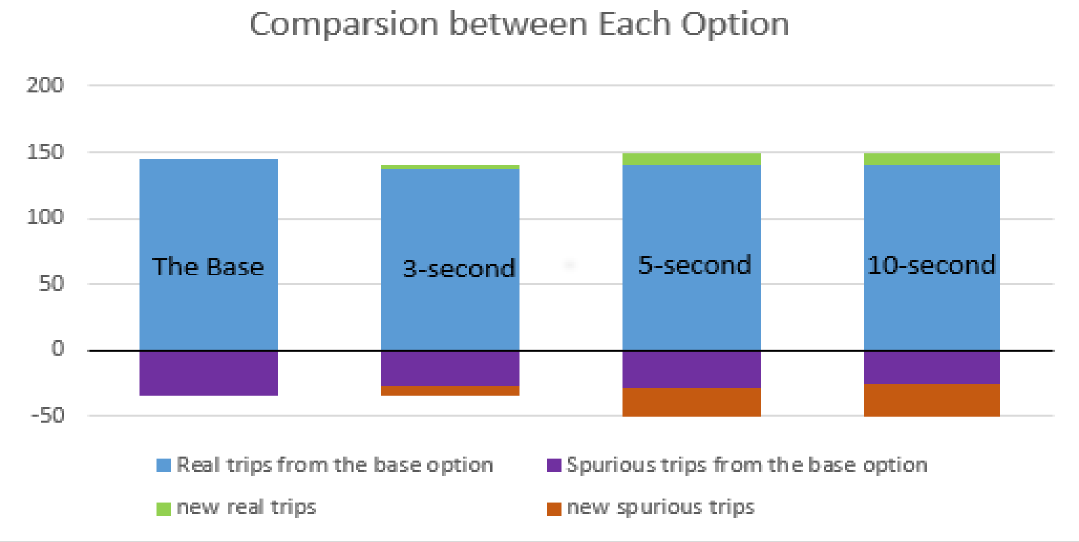

FIGURE 4.2 Overall Change in Total Number of Real and Spurious Trips for Each Option (Oxford Data)

In that case, the 5-second seems to be the best option. The benefit from this is that the total number of points would be dramatically reduced (i.e., one fifth of the base option), which will speed up the processing work. This result applies only to trip identification, however, and would need to be checked also for mode and purpose inference. This analysis also indicates that, due to stringent rules, the software mistakenly deleted some real trips.

4.2 Results of Comparison between Different Thresholds of Dwell Time

Six options were run by G-TO-MAP in this study. This analysis focuses on the trips that needed to be split, especially for those stops that are less than 120 seconds. It is expected that the shorter the threshold of dwell time, the more short duration stops can be identified. For the Sydney data, according to table 4.1, 33 trips failed to be split when the 120-second rule was applied. By reducing the threshold of dwell time, more real stops can be identified. According to Table 4.4, if a 15-second rule applies to the processing work, two thirds of those 33 trips can be found, which would include all the stops that are less than 120 seconds. A 90-second rule found 8 more short duration stops. However, new spurious stops were also added. For the 15-second rule, 110 spurious stops were identified. Given that the total number of trips is 259, 110 (42.5%) is too many to be accepted. The majority of spurious stops were generated due to traffic signals (61.3%, 69% and 82.3% for the 15-second, 30-second, and 45-second rules, respectively, and 100% for the 60-second, 75-second, and 90-second rules).

TABLE 4.4 Comparison of Processing Results between Different Minimum Break Time Settings (Sydney Data)

Consequence	15s	30s	45s	60s	75s	90s	120s
	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops
New real stops	22	19	16	13	9	8	N/A
New spurious stops (congested road)	4	3	4	0	0	0	N/A
New spurious stops (waiting for signals)	68	60	51	30	21	9	N/A
New spurious stops (train stations/bus stops)	38	24	7	0	0	0	N/A
Total new spurious stops generated	110	87	62	30	21	9	N/A
Total trips not split	11	14	17	20	24	25	33

N/A= not applicable

For the Oxford data, results are similar. However, since the proportions of walking and cycling trips are higher in Oxford than Sydney, there are more short duration trips (less than 2 minutes) in Oxford, where most of those trips occur before or after a mode change (e.g., from walk to bike, or vice versa). Some trips are often too short which leads to a failure to detect a mode change. So a relatively large number of trips cannot be split in Oxford due to those short duration trips (Shen and Stopher, 2013). From Table 4.5, even with the 15-second option, only 14 (out of 54) new real stops can be found.

TABLE 4.5 Comparison of Processing Results between Different Minimum Break Time Settings (Oxford Data)

Consequence	15s	30s	45s	60s	75s	90s	120s
	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops	Trips/ stops
New real stops	14	10	10	4	1	1	N/A
New spurious stops (congested road)	9	8	3	1	1	1	N/A
New spurious stops (waiting for signals)	14	8	6	0	0	0	N/A
New spurious stops (train stations/bus stop)	28	21	15	9	7	3	N/A
Total new spurious stops generated	51	37	24	10	8	4	N/A
Total trips not split	40	44	44	50	53	53	54

N/A= not applicable

Figure 4.3 and 4.4 demonstrate the change in the total number of real and spurious stops for different dwell time settings. From the graphs, it seems that the results are similar. The total number of trips that were not split decreases as the dwell-time setting decreases, while the number of spurious trips increases. There is a cross point between these two curves, which seems to indicate that the optimal threshold of dwell time is between 45 seconds and 60 seconds.

However, the value of this optimal threshold may depend on the specific data, which means that a value between 45 seconds and 60 seconds is not necessarily the best for all data sets. In this study, with the 45-second option, while 9 more new real stops were identified than the 60-second option in total, it generated 46 more spurious stops than the 60-second option. Even if the cost of deleting a spurious stop is less than the cost of splitting a trip, the difference between their costs is not as much as 5 times (i.e., 46/9). Therefore, the 60-second option would be the better option for this study.

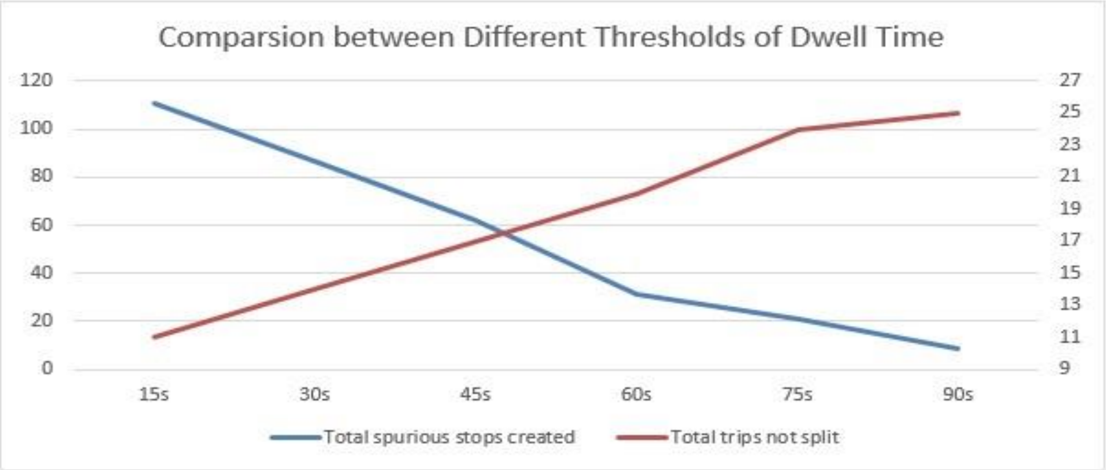

FIGURE 4.3 Comparison of the Total Number of Real and Spurious Stops between Different Thresholds of Dwell Time (Sydney Data)

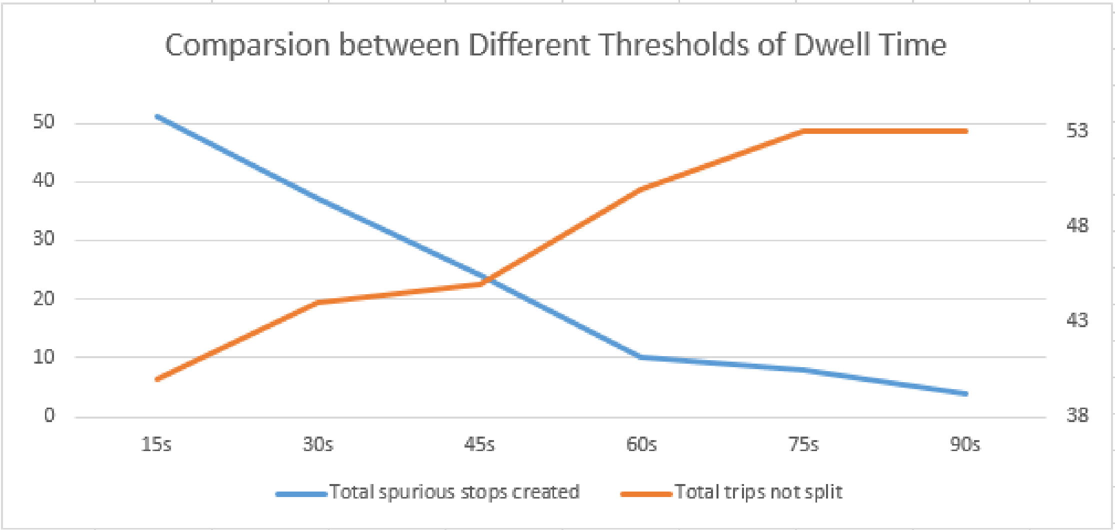

FIGURE 4.4 Comparison of the Total Number of Real and Spurious Stops between Different Thresholds of Dwell Time (Oxford Data)

5 CONCLUSIONS AND FUTURE WORK

This study tested different time intervals to record GPS data. It is suggested that some changes might be made to loosen rules for trip identification. The result of the 5-second option seems to be the best option for this study because more new real trips were identified; however, it would need to be checked also for mode and purpose inference. Therefore, before the test for mode and purpose detection, data should continue to be collected at a one-second interval, but processing for trip identification could potentially sample the data, using five-second intervals between data points.

In terms of the threshold of dwell time, using the 120-second rule would lose 12.7% (Sydney data) and 18.9% (Oxford data) of the real stops. Although many of those real stops can be fixed by reducing the threshold, more new spurious stops will be created at the same time. Therefore, the stop-time rule might be tightened, but the extent of tightening will depend on the relative costs of splitting trips by map editing, versus deleting spurious stops (i.e., combining trips) by map editing. Considering the trade-offs between the number of new real stops and spurious stops, and between the cost of adding real stops and deleting spurious stops, the 60-second option is the best option for the dwell time in this study.

The sample size for this study is relatively small so a larger dataset should be tested in the future using the general public; however, the acquisition of ground truth would be an issue for a new test.

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