Report no. VNTSC-ATMS-04-01

Analysis of the Benefits of Surface Data for ETMS

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Preface

The study on which this report is based has been directed by James Wetherly and Ved Sud of AUA-740 and by Robert Nichols of AND-510. This report is part of an on-going study that has the goal of determining how airport surface data can be acquired, distributed, and used to improve traffic flow management.

Executive Summary

The purpose of this report is to study the benefits that data on activity on the airport surface can provide to the Enhanced Traffic Management System (ETMS). This report uses surface surveillance data generated by a prototype of the ASDE-X system at the Memphis International Airport. It compares three types of messages generated on the basis of this surface data--PS (gate pushback), DS (wheels-up), and AS (wheels-down)--with NAS DZ and AZ messages and also with airline-provided OUT, OFF, and ON messages. Analysis of the reliability of the surface messages was based on two 24-hour data samples from Memphis International Airport. Analysis of the accuracy of the surface, NAS, and OOOI messages was based on 8 days of data; this data was also used to analyze the prediction of the wheels-up time. These studies yielded the following conclusions.

Reliability

- AS and DS messages are generated with a high level of consistency that would make them useful to the operational ETMS.
- PS messages are not yet generated with the consistency that is needed for operational use.
- Spurious messages of all types, although infrequent, present a risk that would need to be addressed before making operational use of the surface messages. It is expected that further refinement of the algorithms for generating the surface messages combined with error checking on the ETMS side could overcome this risk.

Accuracy

- Both the DS and AS messages provide highly accurate event times. Moreover, these messages are also timely; DS messages are received at virtually the same time as DZ messages. Both DS and AS messages would provide good redundancy for the NAS data used by ETMS.
- AS messages are on average received nine minutes earlier than AZ messages. That is, while the wheels-down time in the AS and AZ messages tends to be the same, the AS is available earlier. Use of the AS messages could provide a benefit to ETMS because this would allow flights to be dropped from the Traffic Situation Display in a more timely manner. Moreover, ETMS reports would show a flight status change more rapidly; this would be particularly evident on an updating display like the Flight Schedule Monitor.
- The PS messages appear to be generated on average about five minutes late, and the gate pushback times reported in the PS messages also appear to be on average about five minutes late.

Prediction of Wheels-up

- The PS message, despite the problems mentioned above, would allow ETMS to improve its near-term prediction of the wheels-up time both by improving the average and also by reducing the variability of the prediction. That is, the ETMS prediction of the wheels-up time could be significantly improved, but this improved prediction could only be made ten to twenty minutes in advance.

It should be kept in mind that these results are preliminary since they are based on data at only one airport. These results appear to be firm for Memphis, but it is not known to what degree they apply to other airports.

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1. Introduction

1.1 Background

The Enhanced Traffic Management System (ETMS) has the role of providing information to FAA traffic managers and to National Airspace System (NAS) users so that they can make decisions that lead to the NAS operating in a safe and efficient manner. To fulfill this role, ETMS integrates data from a wide variety of sources. One area where data has traditionally been lacking, however, is the airport surface. Therefore, AUA-740 directed the Volpe Center to begin the process of prototyping the integration of surface data into ETMS.

The work so far has largely consisted of establishing the feed of surface data from the Memphis International Airport (MEM) to ETMS and of using selected surface data events to update the ETMS databases. In particular, the work so far has consisted of the following.

- The full, real-time feed of surface data from MEM to Volpe has been established.
- Estimates of the gate pushback, wheels-up, and wheels-down times are extracted from this data.
- These times are used to update the ETMS data on a test ETMS system.

The general question that needs to be answered is: To what degree can the event times derived from surface data improve the data in ETMS? The purpose of this report is to provide a preliminary answer to this question by focusing on three areas:

1. What is the reliability of the surface message feed? Are messages consistently generated for each expected event? Are all of the messages trustworthy; that is, are there spurious messages that do not correspond to a real event?

2. Will the surface data messages provide better data to ETMS? This breaks into two specific questions:

    - Are the event times derived from the surface data more accurate than the times that ETMS already has? For example, are the wheels-down times derived from the surface messages more accurate than the times that are provided in AZ messages?
    - Are the event times derived from the surface data received earlier than messages that ETMS currently receives? For example, even if the wheels-down time derived from the surface data is the same as the time provided in an AZ message, is the surface event received by ETMS sooner?

3. Can the surface pushback messages be used to improve wheels-up time predictions in ETMS? How do these predictions compare to flights that have airline-provided OOOI data?

The analysis in this report is limited in that it only covers one airport and only for a limited period of time. The tentative plan for the future is to extend this analysis to another airport and to analyze a longer period of time. Moreover, the plan is to determine additional uses that can be made of this data.

1.2 References

Ken Howard, Brent Midwood, and Rick Oiesen, "Interface Control Document for Surface Data," version 2.0, 23 February 2004. This is referred to in this document as the ICD.

Mike Clow, Ken Howard, Brent Midwood, and Rick Oiesen, "Quick Look Report: Analysis of the Benefits of Surface Data," Volpe Center, Report no. VNTSC-ATMS-03-01, September 2003. This is referred to in this document as the Quick Look Report.

2. Derivation of the Surface Data

The ASDE-X system, which the FAA is in the process of fielding, fuses data from a number of sensors to provide a feed of messages that depict the activity on the airport surface. See Appendix A for more discussion of the ASDE-X system. A prototype ASDE-X system is currently providing to the Volpe Center the full feed of surface surveillance data from Memphis. This full surveillance feed of data is *not* what ETMS needs in the long run for three reasons.

- The full surveillance feed contains more data than can be reasonably transmitted in a useful manner to ETMS. For example, on a typical afternoon this data feed peaks at over 400Kbps. If this capability goes operational, the provisional plan is that the surface data would be sent from many airports to the ETMS hubsite; the bandwidth required by the full feed is larger than can be reasonably transmitted.
- The feed contains a great deal of redundancy. That is, the feed contains data that is rapidly updated, and it contains data from multiple sensors. ETMS requirements can be met with a slower update rate and without the redundancy.
- The events that are of interest to ETMS are not clearly distinguished in the feed. For example, there are frequent reports of aircraft position, but there is no explicit indication in the feed that a flight has lifted off.

The prototype solution that Volpe has developed to deal with these facts is called the Event Extractor. The Event Extractor processes the full surface surveillance feed, infers when the desired events such as wheels-up occur, and provides only these events to ETMS. This narrow stream of derived event data is called the reduced feed.

Looking ahead to a possible operational configuration, the provisional plan is that the Event Extractor would be placed at each airport and would receive the full surface surveillance feed over a local-area network. It would extract the desired events and send only this reduced data feed over a wide-area network to the ETMS hubsite. Appendix A contains a diagram showing the relationship between the ASDE-X system, the Event Extractor, and ETMS.

The input to the Event Extractor is a series of ASDE-X messages giving the position and velocity of a flight. Speaking very roughly, the Event Extractor uses these messages to detect events in the following way.

- Gate pushback: When the Event Extractor first determines that a departing flight is moving and that it has moved a slight distance away from the gate area, it declares a gate pushback event.
- Wheels-up: When the Event Extractor determines that a departing flight has passed the departure end of the runway and is moving above take-off speed, it declares a wheels-up event.
- Wheels-down: When the Event Extractor determines that an arriving flight has passed the arrival end of the runway and has slowed to rollout speed, it declares a wheels-down event.

The algorithms used to detect these events are somewhat complicated due to the need to deal with the vagaries of real-time surveillance data; see Appendix C for details. The beacon code is used to associate a flight ID with a surveillance target.

3. Data Analyzed in This Study

3.1 The Data

The data used in the analysis reported in this document was gathered for Memphis International Airport during February 2004. Data was gathered both from the reduced feed of surface data and also from the ETMS feed. Statistical analysis included all days during which there was continuous data for both feeds; in total this amounted to 8 days of data. In addition, detailed examination of anomalies was performed for data collected from 1800Z on 5 February to 1600Z on 6 February; this study of anomalies was repeated for the period from 1400Z on 19 February to 1400Z on 20 February. (An "anomaly" means that a message showed up in one of the two feeds but without a corresponding message in the other.)

The data for this report was collected differently than for the Quick Look Report. For the present report a prototype version of ETMS was developed to ingest the surface messages and use them to update the ETMS database in a similar manner to how the NAS and OOOI messages are used. ETMS correlates each surface, NAS, and airline message with a database entry using such factors as the flight ID, origin, destination, and time of the event. ETMS updates that entry as appropriate, and logs the results in a transaction file. Each transaction identifies the message ID, the flight (ID, origin, destination, date), the times contained on the message, and the updated ETD and ETA that will appear to the ETMS users. This stream of transactions was fed into an Oracle database. The Oracle database was then used after-the-fact to produce various statistical reports. The analysis of this data is reported in sections 4.2 and 4.3.

The detailed data collection performed on 5-6 and 19-20 February included the Oracle data described above along with a log of all the surface, NAS, and airline messages along with the processing logs. The Oracle database was used to highlight data discrepancies and outliers. Additional scripts were used on the source data to find missing and extraneous messages. These cases were then researched in detail using the data logs. The results of these detailed examinations are reported in section 4.1.

The full data logged for the detailed reliability analysis are:

- The full surface surveillance feed from Memphis.
- The reduced event stream that the Event Extractor sent to ETMS. This included all the gate pushback, wheels-up, and wheels-down messages that were generated for Memphis from the feed of surface data.
- The raw NAS messages received by ETMS.
- The ETMS database transaction logs including all updates processes for surface, NAS, and airline (OOOI) messages.
- Other ETMS processing logs that furthered the analysis.

3.2 Message Types

A precise terminology is needed to describe the various message types discussed in this report. Table 3-1 defines the message terminology used in this report.

Table 3-1: Message Type Definitions

Message ID	Interpretation of this message	Message Source	Compare to
PS	Estimate of the actual gate pushback time	Surface data Event Extractor	OUT
DS	Estimate of the actual wheels-up time	Surface data Event Extractor	DZ, OFF
AS	Estimate of the actual wheels-down time	Surface data Event Extractor	AZ, ON
GS	Estimate of the actual gate arrival time	Surface data Event Extractor	IN
DZ	Estimate of the actual wheels-up time	NAS Host computer	DS, OFF
AZ	Estimate of the actual wheels-down time	NAS Host computer	AS, ON
OUT	Estimate of the actual gate pushback time	Airline CDM message	PS
OFF	Estimate of the actual wheels-up time	Airline CDM message	DS. DZ
ON	Estimate of the actual wheels-down time	Airline CDM message	AS, AZ
IN	Estimate of the actual gate arrival time	Airline CDM message	GS

The IDs of PS, DS, AS, and GS were chosen for this study. DS and AS were derived from the NAS IDs of DZ and AZ by replacing the Z with an S, which stands for surface. Since there is no NAS message corresponding to the gate pushback or gate arrival messages, the IDs of PS and GS was adopted to indicate that this message gives a gate pushback time and gate arrival time, respectively, derived from the surface data. The terms OUT, OFF, ON, and IN were adopted for the airline-provided event times as they are commonly used to refer to the airline data provided for on-time analysis; this is the so-called OOOI data. From now on, this report will use the terms PS, DS, and AS to discuss the surface data. The GS message, though provided by the Extractor, is not used in this report since the gate arrival time plays no role in ETMS.

The format of the PS, DS, AS, and GS messages is given in the ICD referred to in Section 1.2.

4. Results of the Analysis

The analysis is provided in three parts: the reliability of the surface data, the accuracy of the surface data, and the usefulness of the surface pushback times for predicting wheels-up time.

4.1 Reliability

The reliability of the surface data messages can be considered in two senses:

- Is there a surface data message for each actual event?
- Are there spurious surface messages that do not correspond to any event?

Both of these questions were examined using the detailed data collected on 5-6 and 19-20 February 2004. The results from 5-6 February are shown in this section. The analysis of the data from 19-20 February yielded results completely consistent with the 5-6 data.

The analysis of the wheels-up and wheels down events was performed as follows. Both the ETMS transaction logs and raw messages were used to correlate the surface messages and NAS messages. Every flight that had one surface message and one NAS message with similar event times was considered to be a good flight. Every unmatched message was investigated to see whether that flight really operated or not, as indicated by NAS track messages. If the flight operated, it was counted as a case of a missing message; if the flight did not operate, it was counted as a spurious message. Similarly, flights that had an extra DS or DZ were examined to determine the actual operation. All such cases were determined to be the result of a spurious message.

Table 4-1 shows the counts for the departure and arrival message analysis performed using the February 5-6 data set.

Table 4-1: Message Counts

Operation Type	Actual Operations	Both Surface and NAS	Missing Surface (DS/AS)	Missing NAS (DZ/AZ)	Spurious Surface (DS/AS)	Spurious NAS (DZ/AZ)
Departure	551	502	41	8	16	1
Arrivals	549	540	4	5	2	1

This table is interpreted in the following way. If the data were perfect, for every departure there would be both a DZ and a DS. This table shows that out of 551 departures, 502 had the expected data. Out of 549 arrivals, 540 had the expected messages. The most important case of missing data is DS messages. In general, these anomalies can be attributed to outages and incorrect positional reports in the raw surveillance feed; see Appendix B for discussion of the investigation of these messages. Improvements in the Event Extractor algorithms may reduce the number of missing DS messages even further, as outlined in Appendix B The other cases of missing messages were infrequent and are not a cause for concern. One of the values of the surface data is that it provides redundancy for the NAS data; that is, in the rare case that one message type is missing, there is a high likelihood that the other will be received.

The last two columns of the table show the counts of spurious messages. These are messages that do not correspond to an actual flight event. In some cases, there was an extra message for an actual flight. These are the most damaging cases as they can cause a flight to be activated or completed at the wrong time. In other cases, the spurious messages did not correspond to any flight in the ETMS database; these messages are discarded by ETMS and do not cause any particular harm. The spurious messages were also investigated and are discussed in Appendix B.

After the September 2003 Quick Look Report was published, modifications were made to the Event Extractor to eliminate some of the anomalies in the data. It is interesting to compare the new data with the September data to see whether any improvement was actually realized. Table 4-2 shows a comparison of the September and February data for the error cases. Numbers are expressed as percentage of actual operations to normalize them.

Table 4-2: Comparison of September and February Errors

Error Case	September 2003	February 2004
Missing DS messages	4.5%	7.4%
Spurious DS messages	2.7%	2.9%
Missing AS messages	1.6%	0.7%
Spurious AS messages	3.5%	0.4%

Clear improvements have been made in the generation of the AS message, but not in the DS. There is particular concern over the spurious messages. A missing message is usually not harmful since the NAS and surface message serve as backups for each other. However, a spurious message can cause a false activation or completion.

The analysis of gate pushback PS messages was approached differently out of necessity, as there is no NAS message that corresponds to the PS message. However, the analysis is straightforward: each PS message should correspond to a subsequent departure, and each departure should be preceded by a PS message.

Table 4-3 shows the results of the PS analysis.

Table 4-3: PS Message Counts

Number of Departures	Good PS	Spurious PS
551	231	6

The number of PS messages is very low and would have to be much higher for ETMS to make good use of this data. The low number can be attributed to two reasons:

- The surface surveillance around the gate areas is inconsistent.
- Some flights do not turn on their transponders while in the area designated as the gate area by the surface data extractor.

The existence of systematic, external factors influencing the generation of the PS messages is supported by the fact the PS messages were generated for only 4 carriers (FDX, FLG, MES, and NWA) and no GA flights, while DS messages were generated for 26 carriers and many GA flights. The percentage of flights with PS messages varied widely among these four carriers, as shown in Table 4-4.

Table 4-4: Flights with PS by Carrier

Carrier	Flights with PS
FDX	69%
FLG	11%
MES	45%
NWA	67%

The table would indicate that either the surveillance for the FDX and NWA gate areas is far better than other areas, those pilots have better procedures for turning on transponders earlier, or some combination of the two.

The spurious messages consisted of the following cases:

- Three flights for which the PS was generated very close in time to the DS. This would not cause a major problem for the use of this data.
- One PS for a flight that never operated (this same "flight" also had a DS message). This message was rejected by ETMS.

- One flight for which two extra PS messages were generated after the flight was active. ETMS rejected these messages.

Although spurious messages remain a concern, these particular examples would not cause any major problem for ETMS.

In summary, the following conclusions can be drawn about the reliability of the surface messages:

- DS and AS messages are generated in enough cases be useful to ETMS, whereas PS messages would have to be generated much more frequently to be useful.
- Spurious messages have been almost eliminated for AS messages, but remain a problem for DS and PS messages. For ETMS to use these messages, the spurious messages would have to be addressed through some combination of improvements in the Event Extractor and error checking in ETMS.

4.2 Accuracy

The accuracy analysis was performed in two parts: comparing the surface data to the NAS data and comparing the surface data to the OOOI data. In both parts, the analysis was performed in the same manner. For each message pair (e.g., DS and DZ), all flights were pulled out of the Oracle database for which ETMS had logged both messages. Two comparisons were then made for each message pair:

- The time at which the surface message was received by ETMS was compared to the time at which the NAS message was received. This comparison is used to determine whether the surface data would provide more timely information to ETMS regarding the status of a flight.
- The event time in the surface message was compared to the ETMS event time generated from the NAS message. This comparison is used to determine whether the surface data would give ETMS a more accurate estimate of when a flight actually took off or landed.

It should be noted that ETMS does not use the event time from an AZ message if that time has a prefix of "E". "E" times on AZs have been found to be quite inaccurate. When ETMS processes an AZ with an "E" time, instead of using the time in the AZ message, it estimates the actual wheels-up time by using an algorithm that combines the time the message was received with recent TZ (track) messages for the flight. Almost all (around 99%) AZ messages received for MEM have "E" times.

The following sections present the results of these comparisons.

4.2.1 Compare Surface and NAS Messages

Figure 4-1 shows a comparison of the DS and DZ received times.

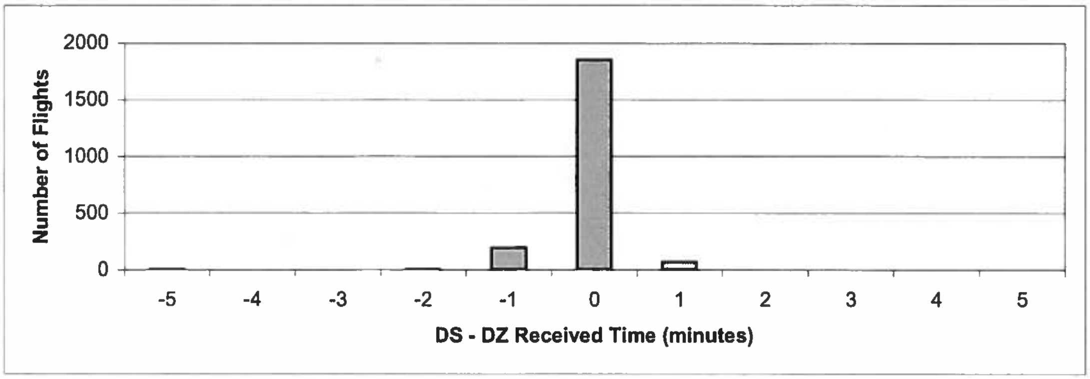

Figure 4-1: DS – DZ Received Times

In the vast majority of cases, the DS and DZ message were received during the same minute. In all cases, the messages were received within one minute of each other. The conclusion is that for practical purposes the DS and DZ messages are received at the same time, and neither the surface data nor the NAS data has an advantage over the other in this regard.

(Note on the interpretation of charts in this report: As the legend of Figure 4-1 states, the times reported are derived by subtracting the DZ received time from the DS received time. The times are represented as minutes elapsed since a base time, which means that a larger number represents a later time. Therefore, when the difference is positive, this means that the DS time is later and the DZ time is earlier; when the difference is negative, this means that the DS time is earlier and the DZ time is later. Other charts in this report are interpreted in the same way. That is, if the legend is X – Y, then a positive difference means that X is later and Y is earlier, and a negative difference means that X is earlier and Y is later.)

Figure 4-2 shows a comparison of the DS and DZ event times.

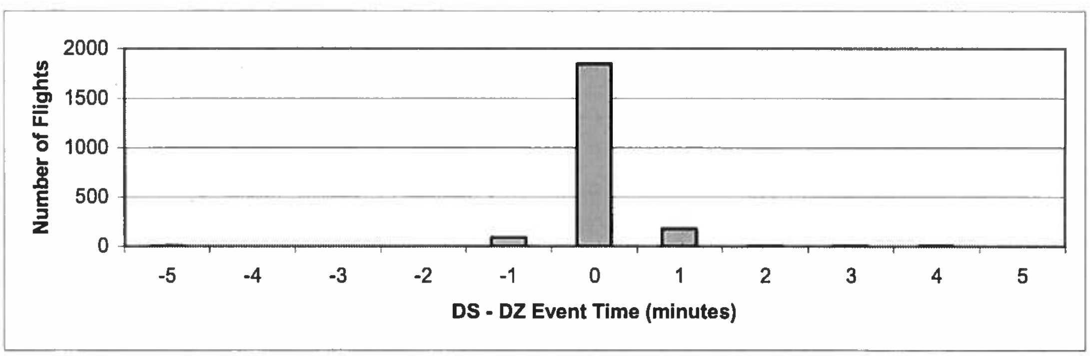

Figure 4-2: DS – DZ Event Times

Again, the majority of the messages indicated times within the same minute and all were within one minute. The conclusion is that the wheels-up times given in the DS and DZ messages are so close that for practical purposes they are the same, and neither the surface data nor the NAS data has an advantage over the other in this regard.

Both the departure received and event times show similar behavior to that observed in the September 2003 Quick Look Report.

Figure 4-3 shows a comparison of the AS and AZ received times.

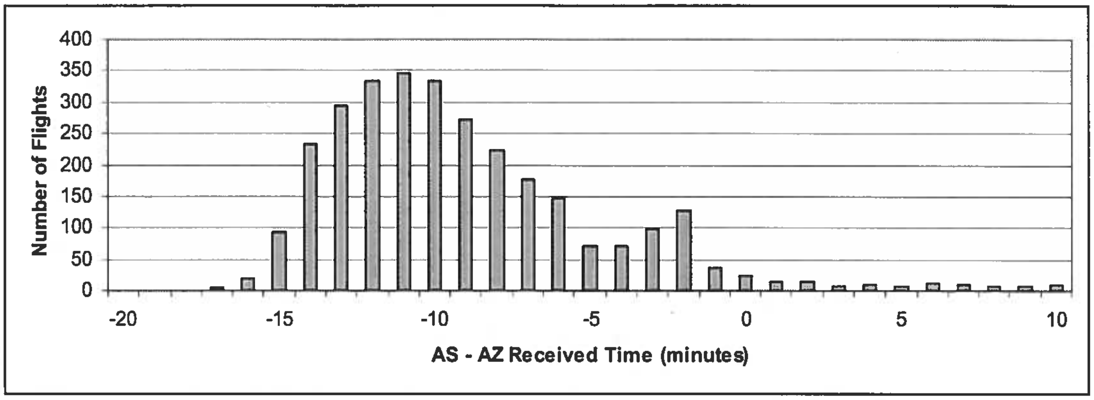

Figure 4-3: AS – AZ Received Times

Unlike the departure messages, there is a marked difference between the AZ and AS received times. The AS messages are received on average 9 minutes prior to the AZ messages, and often up to 15 minutes earlier. Further examination indicates that the AS is received in a timely fashion; it is the AZ messages that are late. The conclusion is that the surface data provides a significant advantage over the NAS data in the time that the wheels-down times are received. This behavior is consistent with that observed in the September 2003 Quick Look Report.

Figure 4-4 shows a comparison of the AS and AZ event times.

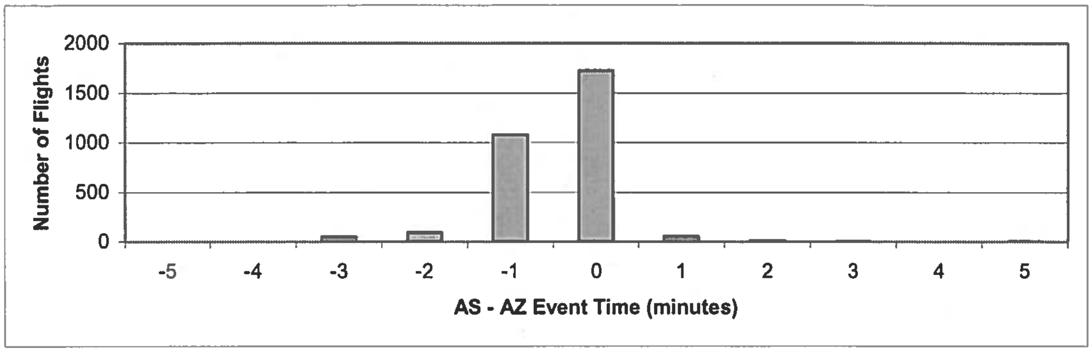

Figure 4-4: AS – AZ Event Times

As with the departure messages, the arrival event times show a high degree of correlation. The majority of the event times are in the same minute and all are within one minute. There is a slight bias, with the AS event times tending to be slightly earlier than the AZ event times. The conclusion is that the wheels-up times given in the AS and AZ messages are so close that for practical purposes they are the same, and neither the surface data nor the NAS data has an advantage over the other in this regard.

The arrival time event comparison shows a noticeable improvement over the September 2003 data. Figure 4-5 shows the event comparison data from September. This improvement may be attributed to changes in ETMS processing of AZ messages with "E" times since the Quick Look Report. The ETMS 7.7 release, which was fielded in October 2003 included changes in estimating the actual arrival time using TZ data if the AZ has an "E" (estimated) time rather than an "A" (actual) time. These changes would particularly affect cases where the AZ is received much later than the actual wheels-down time, as it typically is at MEM.

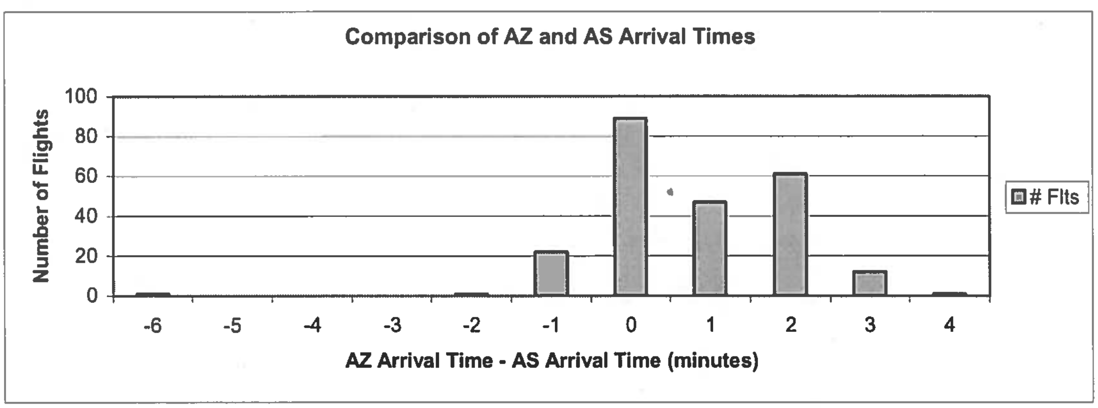

Figure 4-5: September 2003 AS – AZ Event Times

In summary, the DS and DZ messages are virtually equivalent in accuracy and timeliness. AS and AZ messages provide equivalent accuracy in the event times, but the AS messages are generated in a much more timely manner. Both messages would provide a benefit to ETMS as a source of redundancy to fill in for the occasional missing NAS message. The AS would provide a much greater advantage by allowing ETMS to know the wheels-down time very close to the wheels-down event. It should be noted that this advantage may not exist at every airport. It is not believed that the AZ messages arrive late for every airport in the NAS.

4.2.2 Compare Surface and OOOI Messages

The second part of the analysis consists of comparisons of the surface messages with the OOOI messages. The PS is compared with the OUT message, as this is the only other source of gate pushback time. The DS and AS are compared to OFF and IN, respectively, for completeness. It would also be valid to compare DZ and AZ to OUT and OFF. However, since the DS is statistically equivalent to the DZ and the AS is superior to the AZ, nothing new would be learned from these additional charts. It should be noted that the airline OOOI messages have not been previously analyzed for their timeliness and accuracy, so one must be careful in interpreting these results.

Figure 4-6 shows the received time comparison for the PS and OUT messages.

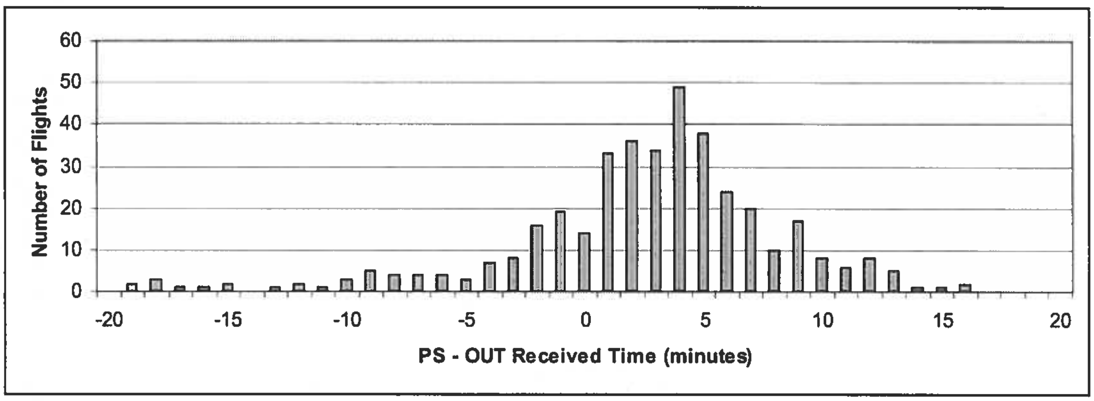

Figure 4-6: PS – OUT Received Times

Two things are readily apparent from this chart:

- There is a good degree of variability in the message-received times.
- The PS messages are typically received later than the OUT messages.

Neither of these observations is surprising. The PS message is dependent on surveillance data, which is not consistent for the entire gate area, and on transponders being turned on, which depends on the flight crew. It is expected that the surveillance equipment will not pick up aircraft movement in some areas until the flight is well away from the gate. Furthermore, there is no expectation that the airline-generated OUT messages would be sent in a very timely manner, as these have not been previously analyzed. It is known, for example, that since ACARS messages are expensive, sometimes an airline will batch its messages; that is, it might save the OUT message and send it as the same time as the OFF message.

Figure 4-7 shows the PS and OUT event times.

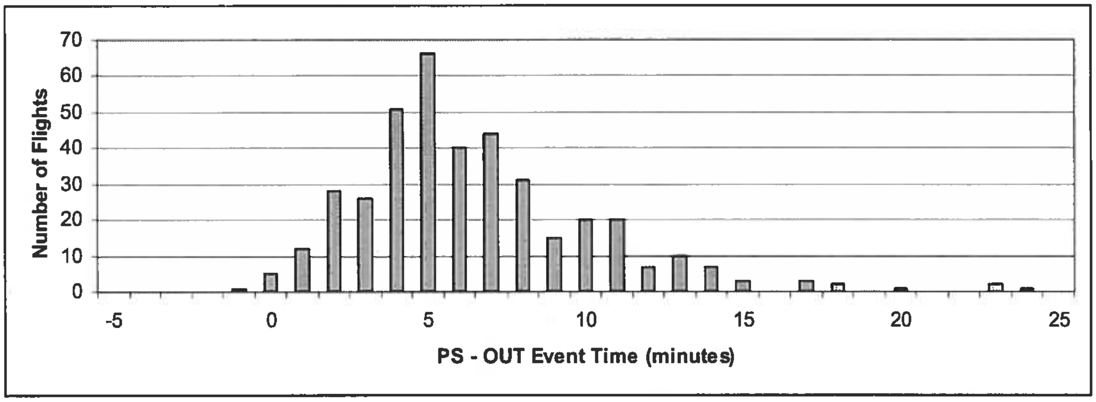

Figure 4-7: PS – OUT Event Times

The data event data shows a similar distribution to the received times, although several outliers are no longer present. The tendency for the PS event time to be later than the OUT event time can be attributed to the same factors as the received times.

Figure 4-8 shows a comparison of the DS and OFF received times.

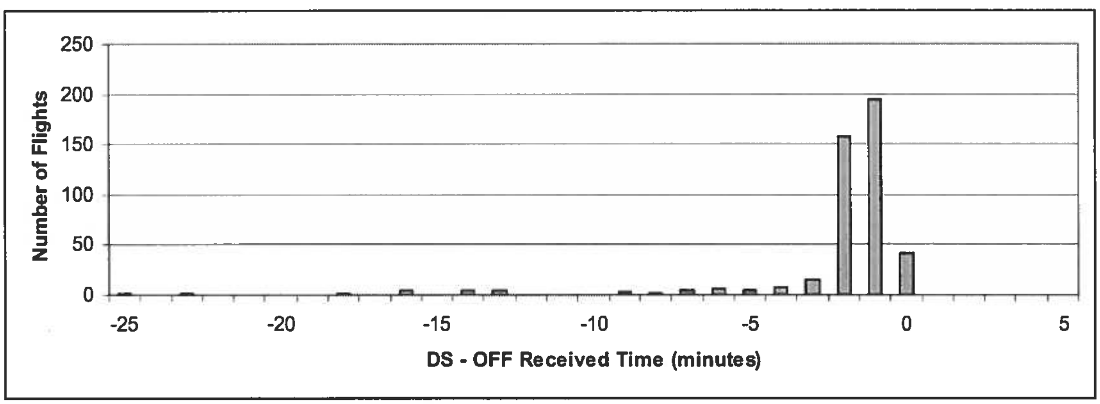

Figure 4-8: DS – OFF Received Times

Because the DS has already shown such a high correlation with the DZ messages, this analysis is really about the accuracy of the OFF messages. The data shows that the OFF message always comes in later than then DS, and can be up to 25 minutes later.

Figure 4-9 shows the event time comparisons for the DS and OFF messages.

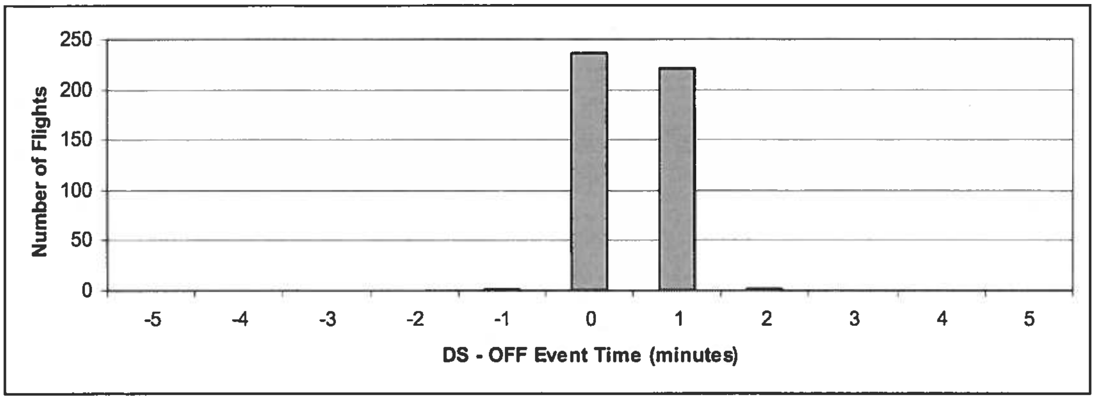

Figure 4-9: DS – OFF Event Times

The event times show a high degree of correlation, with a slight bias towards the OFF time being earlier than the DS time.

Figure 4-10 shows the comparison of the AS and ON message-received times.

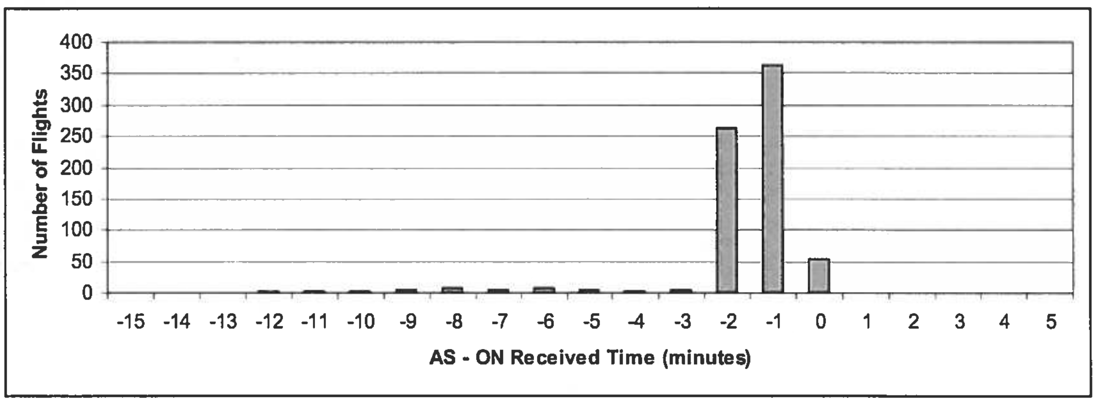

Figure 4-10: AS – ON Received Times

Again, the AS has been demonstrated to be a timely message so any discrepancies can be attributed to the ON message. As with the OFF messages, the ON messages come in consistently after the PS messages, with a large number of them being within 2 minutes.

Figure 4-11 compares the AS and ON event times.

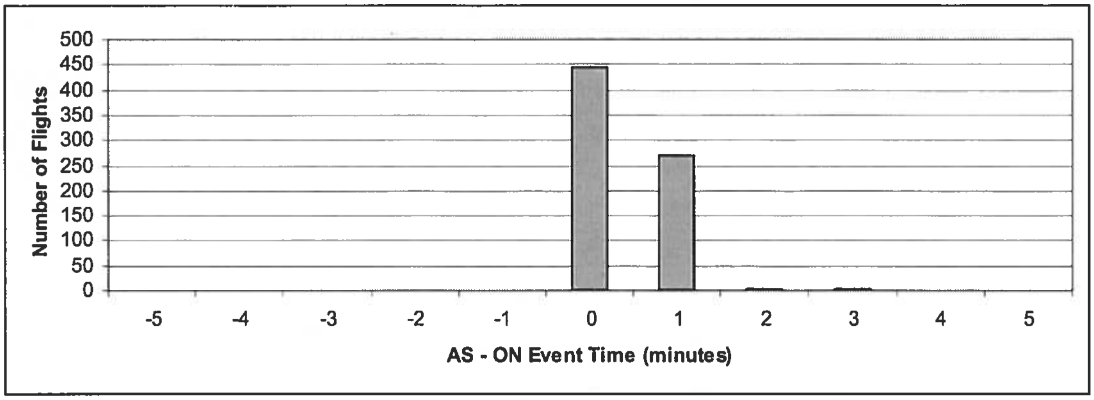

Figure 4-11: AS – ON Event Times

Again, there is a close correlation between the event times, with the ON times tending to be very slightly earlier than the AS times.

The main goal of this portion of the analysis is to establish the accuracy and timeliness of the surface PS message. The only point of comparison is the airline OUT message, which has not been previously analyzed for accuracy and timeliness itself. However, if one can infer the properties of the OUT message from the OFF and ON messages, one would conclude that it contains accurate event data but is not always received by ETMS in a timely manner. Based on this inference, one would conclude that the PS message consistently provides an event time that is later than the actual event, 5 minutes later on average. Since the PS message is generated at the event time, it can be conjectured that the PS message is also received about 5 minutes after actual gate pushback

As for the benefit to ETMS, these conclusions and conjectures suggest that if ETMS has OOOI data, then there is perhaps a marginal benefit to its having the PS message. It is the case, however, that ETMS often does not have OOOI data, so there is still room for the PS message to provide significantly useful information to ETMS; see the next section for further discussion.

4.3 Predicting Departure Time from Pushback

A promising potential use of the surface data is to allow ETMS to improve its predictions of wheels-up times by using the pushback messages. Currently, ETMS predicts a wheels-up time in one of two ways. (Note: CDM messages refer to a real-time feed of schedule updates that airlines provide to ETMS.)

- If an airline sends a predicted wheels-up time in a CDM message, ETMS uses that time.
- Otherwise, ETMS uses the best available predicted gate pushback time (airline-provided in a CDM message, flight plan, or OAG) and derives the wheels-up time by adding a historically determined amount of time, which is called the ground time.

In either case, ETMS relies mainly on a prediction made while the flight is still at the gate. For many flights, this is the only prediction available until the flight takes off. With the introduction of gate pushback data, ETMS can explore other ways to improve the wheels-up prediction, such as:

- When ETMS receives a pushback message, it could update the predicted wheels-up time by using the pushback time with some estimation of the expected time that elapses between pushback and wheels-up (taxi time plus departure queue delay).
- When ETMS observes that a flight has not pushed back on time, it could start moving the expected wheels-up time further into the future.

The latter option is an indirect benefit, and would require confidence that a PS message will, in fact, be generated for every flight. The former option is available for any flight that gets a PS message, and is the more direct benefit to ETMS. Therefore it is the former option that is analyzed here.

The goal of this analysis is to determine how an ETD prediction based on the actual gate pushback message would compare to the ETD prediction made before the gate pushback. All flights were grouped together for this analysis; that is, flights for which ETMS receives an airline predicted wheels-up time, and flights for which ETMS predicts the wheels-up time. Three values were compared.

1. The ETD predicted at the time the FZ was processed. This yields a fairly near-term prediction either by ETMS or the airline that is not yet based on an actual gate pushback.
2. The ETD predicted at the time of the gate pushback. This is either the airline provided time, or the gate pushback time plus 10 minutes.
3. The gate pushback time plus the ETMS historical ground time for that flight.

The first ETD is the one currently used by ETMS and provides the baseline for comparison. The second ETD uses what is currently being produced by the ETMS prototype software. The third ETD uses the ETMS historical ground time estimate, which does not correspond exactly to the ground time needed for this use. That is, the ETMS historical ground time estimate is measured from *scheduled* gate pushback to the actual wheels-up, whereas what is really needed is an estimate from *actual* gate pushback to wheels-up. Nonetheless, it seems a valid point of comparison.

Figure 4-12 shows the comparisons of these three ETDs.

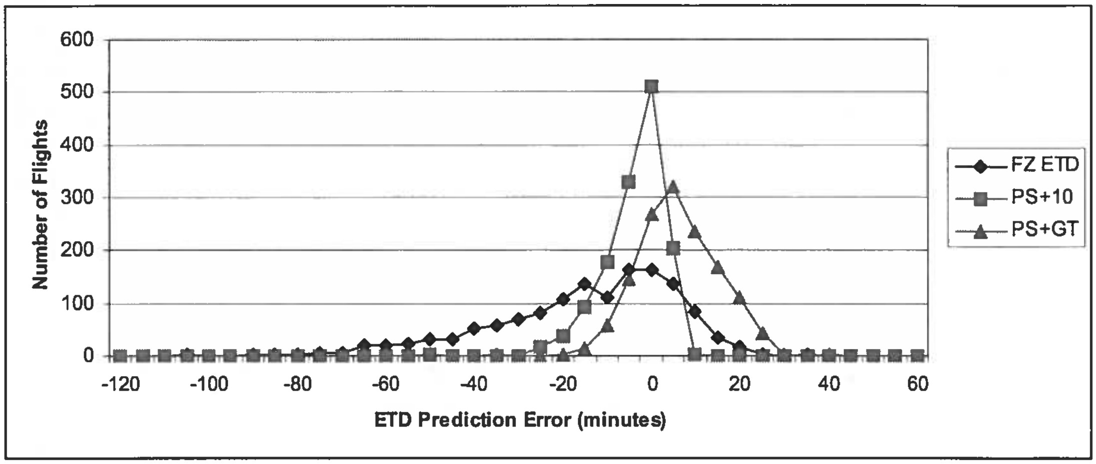

Figure 4-12: ETD Comparisons Using PS Message

The line labeled *FZ ETD* represents the ETD currently used by ETMS. The *PS + 10* line shows the ETD produced by adding a constant 10 minutes to the PS time. The *PS+GT* line shows the ETD produced by adding the ETMS historical ground time.

The figure indicates a dramatic improvement in the ETD prediction by either use of the PS message. The average absolute error is reduced from 18 minutes for the FZ ETD approach to 10 minutes for the PS+GT approach to 5 for the PS+10 approach. In addition to this improvement in the average prediction, both methods demonstrate a large reduction in the variability of the error.

It is necessary to point out that this improvement in ETD accuracy can only be achieved fairly close to the departure time; that is, when the PS message is received. Figure 4-13 shows the PS received time as compared to the departure time. Note that some of the variability in these times may be due to the manner in which the PS is being generated by the event extractor.

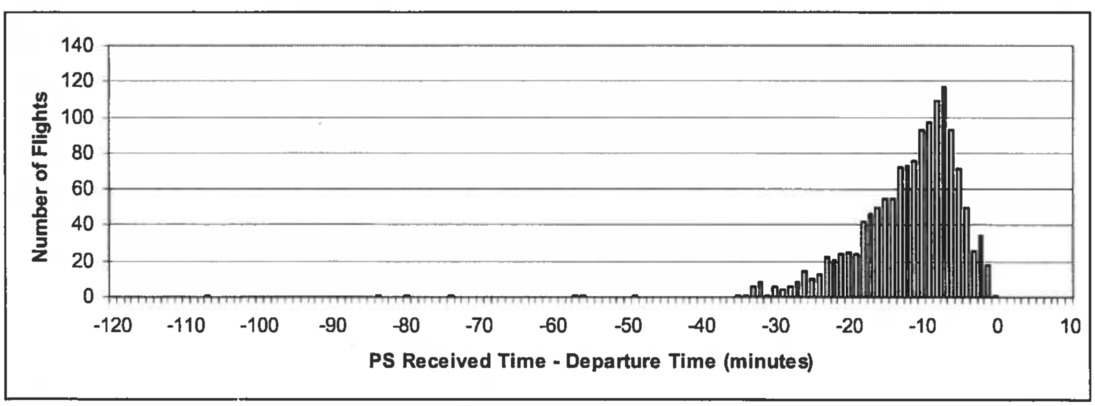

Figure 4-13: Comparison of PS Received Time and Departure Time

It should also be noted, that if the PS message was being reliably generated, ETMS could delay flights that had not pushed back and gain further improvements in ETD accuracy.

In summary, even simplistic use of the PS message shows a good degree of promise for improving close-in ETMS ETD prediction accuracy.

5. Conclusions

This report has compared PS (gate pushback), DS (wheels-up), and AS (wheels-down) surface messages with NAS DZ and AZ messages and also with airline-provided OUT, OFF, and ON messages. Analysis of the reliability of the surface messages was based on two 24-hour data samples from Memphis International Airport. Analysis of the accuracy of the surface, NAS, and OOOI messages was based on 8 days of data; this data was also used to analyze the prediction of the wheels-up time. These studies yielded the following conclusions.

Reliability

- AS and DS messages are generated with a high level of consistency that would make them useful to the operational ETMS.
- PS messages are not yet generated with the consistency that is needed for operational use.
- Spurious messages of all types, although infrequent, present a risk that would have to be addressed before making operational use of the surface messages. It is expected that further refinement of the Event Extractor and error checking on the ETMS side could overcome this risk.

Accuracy

- Both the DS and AS messages provide highly accurate event times. Moreover, these messages are also timely; DS messages are received at virtually the same time as DZ messages. Both DS and AS messages would provide good redundancy for the NAS data used by ETMS.
- AS messages are on average received nine minutes earlier than AZ messages. That is, while the wheels-down time in the AS and AZ messages tends to be the same, the AS is available earlier. Use of the AS messages could provide a benefit to ETMS because this would allow flights to be dropped from the Traffic Situation Display in a more timely manner. Moreover, ETMS reports would show a flight status change more rapidly; this would be particularly evident on an updating display like the Flight Schedule Monitor.
- The PS messages appear to be generated on average about five minutes late, and the gate pushback times reported in the PS messages also appear to be on average about five minutes late.

Prediction of Wheels-up

- The PS message, despite the problems mentioned above, would allow ETMS to improve its near-term prediction of the wheels-up time both by improving the average and also by reducing the variability of the prediction. That is, the ETMS prediction of the wheels-up time could be significantly improved, but this improved prediction could only be made ten to twenty minutes in advance.

It should be emphasized that the approach to the wheels-up prediction used in this report is extremely simplistic. Investigation should be made of using the surface data to track and predict the ground times, including departure queue delays. It is expected that such an approach would yield even better results.

It is also worth stressing that further work on the algorithms used by the Event Extractor would improve the accuracy and reliability of the surface data, perhaps dramatically.

In closing, it should be kept in mind that this report is still preliminary since it is based on data at only one airport. These results appear to be firm for Memphis, but it is not known to what degree they apply to other airports.

Appendix A: Surface Surveillance Architecture

The Event Extractor, which was mentioned in Section 2, consumes the full surface surveillance feed, uses this feed to determine when various events of interest occur, and sends a reduced feed containing only these events to ETMS. In the currently fielded prototype system, the full surveillance feed utilized by the Event Extractor is provided by the SafeFlight 21 Surface Surveillance system at Memphis International Airport. The SF21 system was used as a prototype during the design and requirements phases of the Airport Surface Detection Equipment (Model X), or ASDE-X, program. It is envisioned that as ASDE-X is deployed at various airports, it will provide the surface surveillance feed required by the Event Extractor.

The current SF21 system at MEM is shown in Figure A-1 below. The Standard Terminal Automation Replacement System, or STARS, was recently installed at MEM. Prior to STARS installation, the surveillance system was being fed by the ARTS-IIIA and ODS Gateway at MEM.

The heart of the SF21 surveillance system is the Surveillance Server (SS). This component receives several sources of surveillance and automation information, and combines them together in a process known as data fusion. The fusion process results in track information based on more than one surveillance source. A benefit of this process is the ability of the fusion processor to continue sending data even if a certain surveillance source is unavailable. The fusion processor also uses flight information from the automation systems, e.g., STARS; this allows the flight ID and other flight data to be correlated to a track.

The Socket Relay Server (SRS) is responsible for data dissemination and data filtering. It allows data consumers to receive appropriate track data generated by the SS. It provides security features to assure that only authorized consumers receive data. It also provides data filtering capability to ensure that certain sensitive information is not transmitted to specific data consumers. Examples of this include the ability to remove competitor's data from certain airline feeds, or the ability to remove certain flight IDs, such as Air Force 1 or other military flight IDs, from non-FAA feeds.

The SS and the SRS make up the ASDE-X prototype system. When ASDE-X systems are fielded, they will include the capabilities of the SS and the SRS, and thus will provide the surveillance feed necessary for the event extraction process.

STARS, the Flight Plan Unit (FPU), and the Terminal Automation Interface Unit (TAIU), combine to provide flight plan information to the Surveillance Server. This information allows the SS to attach flight IDs and other flight information to the surveillance tracks generated by the fusion process. The FPU associates a beacon code with a flight ID, and the secondary radar and multilateration systems associate a beacon code with a track. The SS can then match these beacon codes to associate a flight ID with a track.

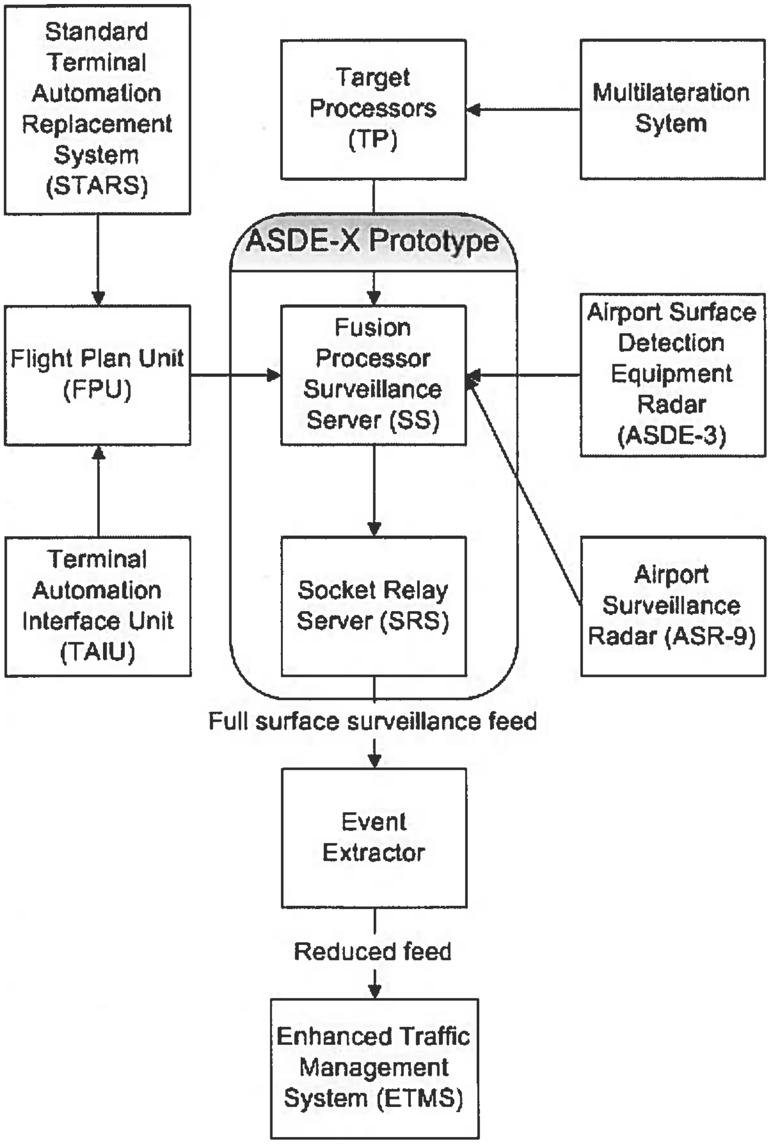

Figure A-1 SafeFlight 21 Surveillance System at MEM

Also shown in Figure A-1 are the raw surveillance sources at Memphis International Airport, including the surface surveillance radar (ASDE-3), the terminal area radar (ASR-9), and the multilateration system.

Multilateration is a technology that calculates the position of aircraft based on the timing of beacon code transmissions received at Remote Unit (RU) ground stations. Since the position of the aircraft must be determined in three dimensions, at least four RUs are required. The multilateration installation at Memphis is composed of RUs on the airport surface, as well as RUs positioned several miles around the airport perimeter. In terminal airspaces, multilateration provides an accurate passive surveillance alternative to active surveillance sources such as radar.

The multilateration system and the ASR-9 radar provide surveillance coverage up to 60 miles from MEM. When fielded, the capabilities of the ASDE-X system will include the ability to accept other surveillance sources as input, for example, Automatic Dependent Surveillance Broadcast (ADS-B).

The current data format provided as output by the SRS at Memphis is a custom format developed by the Airport Surface Division at the Volpe Center for use in the prototype system. This message format contains various information about a track, including positional information, time stamps, aircraft type, flight ID, beacon code, and velocity, among others. When fielded, the capabilities of the ASDE-X system will include the ability to provide various data formats to consumers, for example, Asterix CAT-11.

Appendix B: Algorithmic Issues in the Event Extractor

B.1 Handling Wide-band Surface Surveillance Outages and Problem Areas

In initial tests of the Event Extractor reported in the Quick Look Report, it did not generate DS and AS messages for a significant number of flights. A large percentage of these flights can be attributed to bad surveillance in a localized area over a short period of time.

For instance, an area just north of runway 36L seemed to drop a significant number of departures from surveillance coverage just after crossing the runway threshold. This behavior seemed to occur for short periods of time, somewhere on the order of ten minutes. This behavior might be attributed to weather or other atmospheric conditions interfering with the surveillance system. This behavior also occurred but less frequently in other parts of the terminal area covered by the surface surveillance system.

These problems were addressed in the Event Extractor software by more intelligently partitioning the surface areas of the airport for use in the event extraction algorithms. A fix for this issue has been developed and deployed, and seems to show improvement in the accuracy of events generated by the Extractor. However, the currently deployed version of the Event Extractor still seems to occasionally miss events, including the DZ events as mentioned in Section 4.1.

Additional accuracy may be gained by partitioning the airport surface into even smaller segments for use by the event generation algorithms. While extreme cases of inaccuracy in the surveillance cannot be effectively handled by the Event Extractor, algorithmic improvements in managing a track's state history may also improve matters.

Finally, maturation of the full surface surveillance system should improve the accuracy of event data. This may occur when the Event Extractor consumes a commissioned ASDE-X feed rather than a surface surveillance prototype such as SafeFlight 21.

B.2 Handling Anomalous Single-Track Behavior

In initial tests of the Event Extractor, a small number of tracks exhibited clearly anomalous behavior as reported by the surface surveillance system. Some of these behaviors are clearly not physically possible; these tracks should be recognized and discarded by the event extraction algorithms.

For instance, tracks have been reported instantaneously accelerating to very high speeds while they are still parked in a gate area. The track "jumps around" the airport display, and after a few seconds, may return to a normal stationary state. This may happen over an extended period of time, or may be localized to only a few seconds. It has also been noted that certain areas on the MEM airport surface are more susceptible to this type of misreporting by the prototype SafeFlight 21 surveillance system.

This type of misreporting by the surveillance system has occasionally "fooled" the event extraction algorithms into reporting an event that did not actually occur. For instance, a plane near the edge of the movement area may suddenly appear to accelerate and move off the movement area. The event extractor would generate a DS message, but the a few seconds later, the tracking anomaly disappears and the track is shown at low speed back on the surface area.

Significant improvement has been made in the Event Extractor's algorithms for event generation. Further testing has shown an increased capability by the Event Extractor to handle such anomalous surveillance instances. Based on the latest data analysis, further improvements can be made by increasing the algorithms reliance on previous state data for a particular track, thus reducing the impact of short term anomalies in surveillance data.

B.3 Improvement of Algorithmic Parameters

In addition to the issues above, certain events were missed due to un-optimized parameters in the event extraction software.

In initial testing, at least one flight did not generate a DS message because it departed below the minimum takeoff speed threshold that was provided to the algorithm.

Also during initial tests, at least one flight did not generate an AS message because it temporarily dropped from the surveillance coverage, and reappeared on the surface after a timeout interval had expired in the algorithm.

These parameters are optimized by analysis and observation. They have been updated in the MEM Event Extractor based on the results of this preliminary analysis and have shown a large improvement in subsequent tests. In the most recent round of tests, no event data issues were attributed to algorithmic parameters.

Appendix C: Currently Implemented Event Extraction Algorithms

The current Event Extractor is providing Out, Off, On, and In data generated not by airlines but from surface data.. Desired events are determined to have occurred by processing the full surface surveillance feed with various event engines implemented in the Event Extractor software. These engines operate simultaneously and independently of one another. The following sections outline the algorithms the various engines use to process the full surface surveillance feed.

Initial analysis of event data has been essential in improving the accuracy of events provided to ETMS. Further data analysis will allow improvements in algorithm design, parameter values, and engine communications, to increase the overall accuracy of event data produced by the Event Extractor.

In general, each event engine processes every surveillance message passed as input by the surveillance server. The event engines maintain state arrays that allow surveillance history for each flight to be analyzed.

C.1 Off Event

When the Off event engine receives a surveillance message, it first determines the flight ID, the velocity, and the position of the flight in question. It then follows the following decision tree in determining if an Off event has occurred.

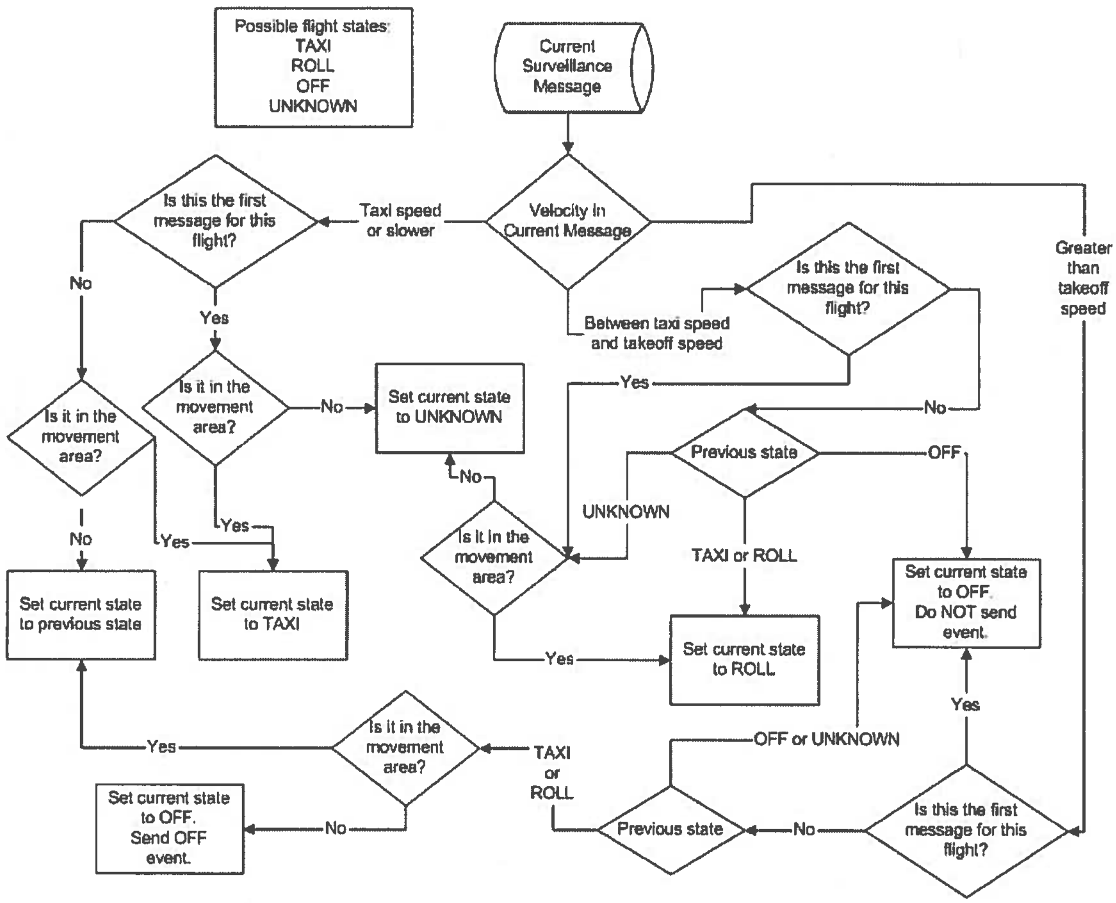

Figure C-1: Off Event Engine Logic

C.2 On Event

When the On event engine receives a surveillance message, it first determines the flight ID, the velocity, and the position of the flight in question. It then follows the following decision tree in determining if an On event has occurred.

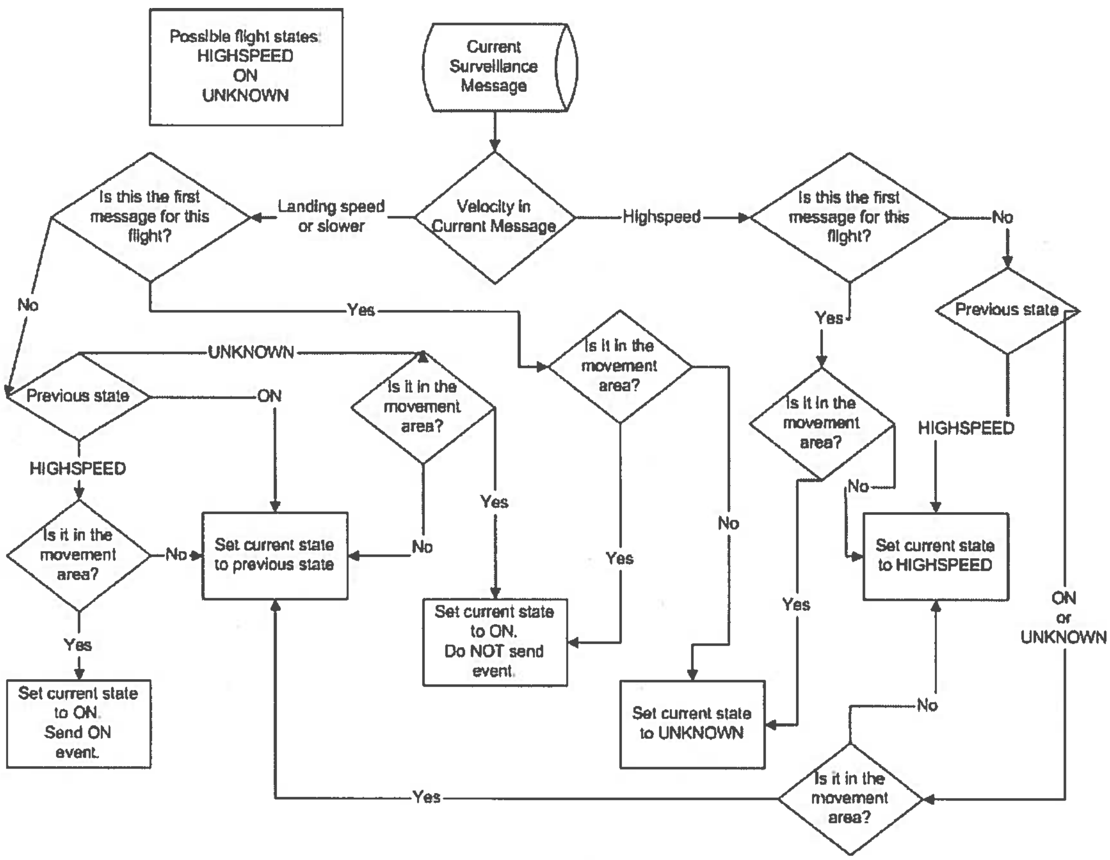

Figure C-2: On Event Engine Logic

C.3 Out Event

When the Out event engine receives a surveillance message, it first determines the flight ID, the velocity, and the position of the flight in question. It then follows the following decision tree in determining if an Out event has occurred.

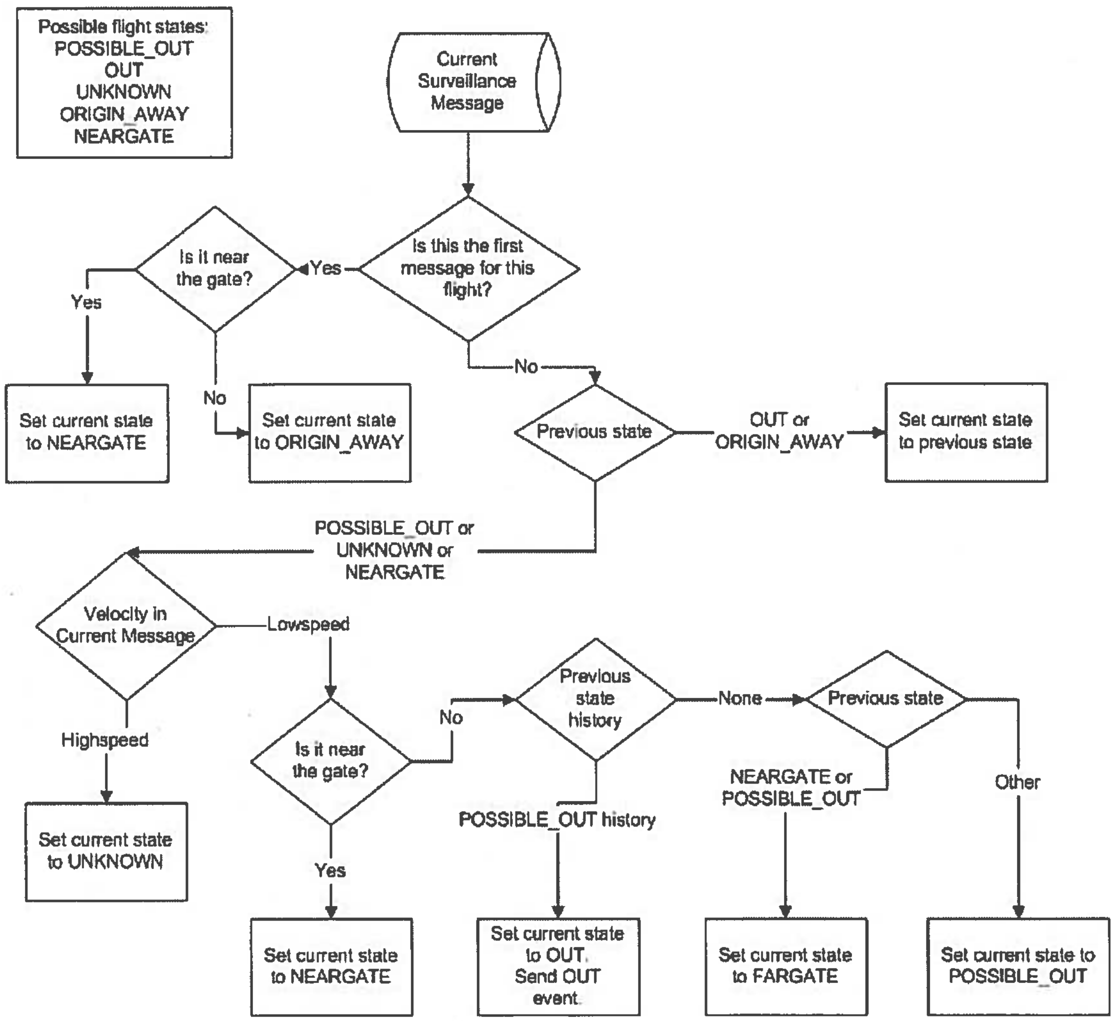

Figure C-3: Out Event Engine Logic

C.4 In Event

When the In event engine receives a surveillance message, it first determines the flight ID, the velocity, and the position of the flight in question. It then follows the following decision tree in determining if an In event has occurred.

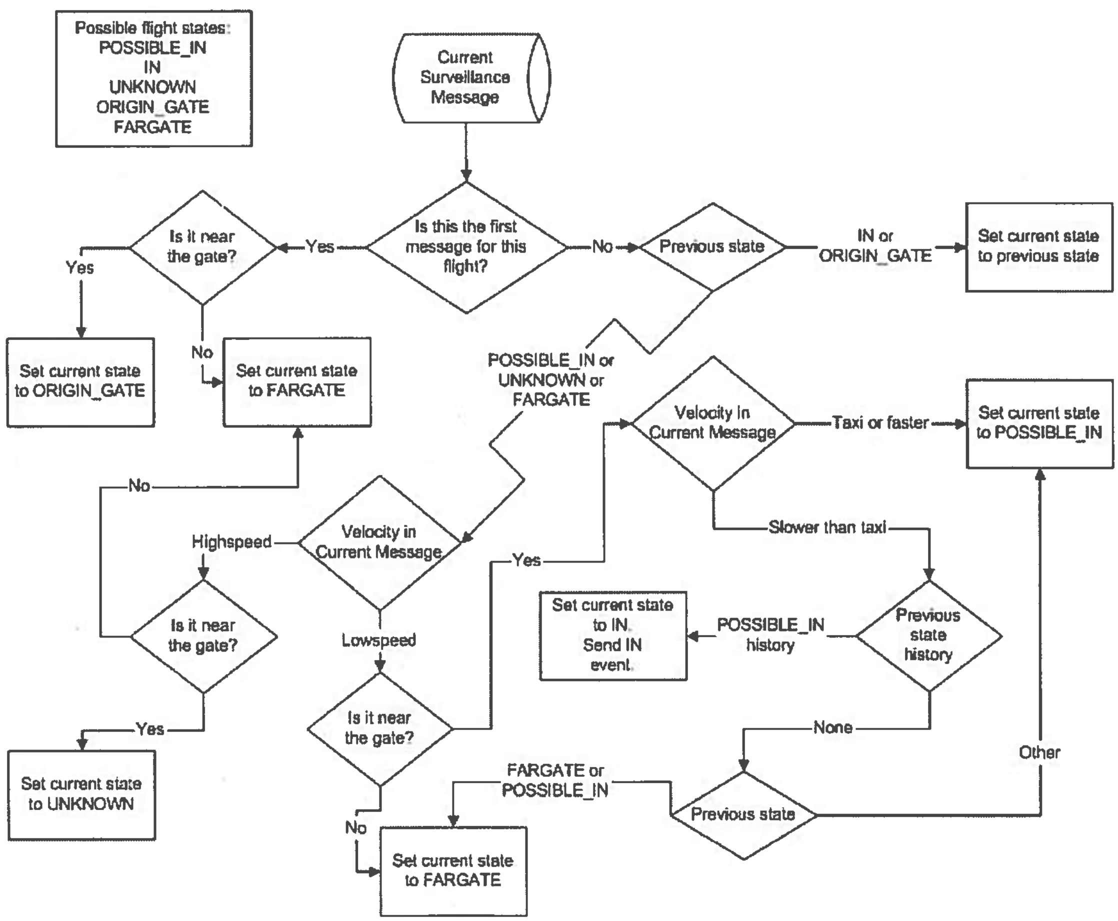

Figure C-4: In Event Engine Logic