Time Synchronization in Emergency Response Time Measurement

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Abstract: Emergency response time reporting requires data provided by multiple systems. Whenever more than one system produces a time stamp, issues of time synchronization across systems manifest. As emergency response time targets are often short (8 minutes or less) and critical to public perceptions of service, errors in reporting these times are unacceptable. This article seeks to quantify the probability and magnitude of such errors through an empirical study of one emergency medical dispatch system.

1 INTRODUCTION

One needs only to "google" the expression "ambulance response times" to find a plethora of government agency and ambulance service provider reports on both targets for and reported performance indicators of response times. The most common definition for response time proffered in these reports is: "the period between when a call is recorded at the emergency operations center to when the ambulance arrives at the patient's address.", see eg. (New South Wales Government, 2016; The Capital Region of Denmark, 2016; Manitoba Canada, 2016). Immediately striking in this definition is the implicit recognition that at least two information system components must interface to yield an accurate response time – the operations center call recording system and the mobile, field reporting unit on-board the ambulance specifying arrival to the scene. The potential for time synchronization issues increases with each additional information and communication technology (ICT) that must interface in a system. This paper examines the response time data from a computer aided dispatch system with the aim of quantifying the prevalence of time synchronization data errors in the measurement of emergency response times.

The paper begins with a short review covering emergency response time targets and computing standards on time data recording and synchronization. Section 3 describes the case study setting. Sections 4 and 5 present the results and a conclusion with directives for improved time data management in emergency medical dispatch (EMD) systems.

2 BACKGROUND

Emergency response time targets, while highly disputed in the literature (Pons and Markovchick, 2002; Pons et al., 2005; Blackwell et al., 2009; Wilde, 2013), are still considered the standard against which ambulance services are measured. One of the most prevalent targets is an 8-minute response time. The National Health Service of the United Kingdom specifies that 75% of all top priority (Red level) calls should be responded to within 8 minutes; for less urgent calls the standard requires response within 19 minutes for 95% of all calls (Wankhade, 2011). Violations of response time service level standards can, in some locations, lead to the revocation of ambulance operating licenses (Clark County, IN, USA, 2014).

Despite these standards there is still wide variation in ambulance response times. Much of this variance can be attributed to the different systems of garnering and reporting such data. This issue is not particular to the UK, in a June 2015 article on the *EMS World* website, Dr. Bruce Moeller notes that "Time is easy to measure – response times are not." He continues by noting that a study in Florida found nine different definitions of response time in use. Interestingly, Dr. Moeller concludes that Pinellas County overcame this problem for the 19 providers in their

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system by using a regional computer-aided dispatch (CAD) system and a fixed definition of response time as the time from agency dispatch until arrival on scene (EMS World, 2015). This implies that the two requisite time stamps recorded by the CAD are considered completely accurate. While there is some basis for this assumption of accuracy as reported in a 1997 article on measuring response intervals in a 911 dispatch system, current time format standards have changed since that time (Campbell et al., 1997).

The International Organization for Standardization's standard ISO 8601 specifies a complete set of date and time formats (ISO, 2004). This standard is based on the Gregorian calendar and is flexible in that it allows one to represent time as both calendar dates and as ordinal dates. The standard also specifies a representation protocol for time zones – again with flexibility as one can specify local time, universal time, or an offset from universal time. Finally, ISO 8601 allows for the representation of time intervals as well. Of course, any standard as flexible as the ISO 8601 can also lead to complexity when used in specific settings. To that end, the Internet Engineering Task Force approved RFC 3339 which simplifies time stamp notation for Internet use limiting the format to yyyy-mm-ddThh:mm:ssZ or +/-hh:mm, where y stands for year, m for month, d for day, T is a character separating date from time, h stands for hour, m for minutes, and s for seconds; the Z is for universal (or Zulu) time or one can specify an offset from universal time (Klyne and Newman, 2002). The World Wide Web Consortium adopts a similar standard for web-based time and date stamps (W3C, 1997).

With regards to EMD, the critical elements to the time stamp standards noted above are the clear use of the yyyy-mm-dd protocol for dates. If one ICT within a system uses the American style yyyy-dd-mm format while another uses the yyyy-mm-dd protocol, then 12 days out of the year would yield reasonable but incorrect time intervals and an additional 11 days worth of data out of every month would yield illogically long intervals. Furthermore, specifying the time zone is also important in emergency medical services as changes between daylight savings time and standard time will influence the calculation of time intervals that span such clock changes. If the components of an EMD system are located in different time zones (eg. a remote server is used to capture and time stamp records), then having the ability to bring all times into one zone for time calculations is critical.

Due to the relative nature of time intervals (eg. a year may be 365 or 366 days depending on a leap year), the ability to accurately perform time related arithmetic is more complex than one might expect. As response time is ultimately the difference between two time stamps, being able to make that subtraction accurately and correctly is important. This calculation is generally performed outside of the ICT or EMD system. Nevertheless, the analytics tools that take possession of the data in order to produce the response time performance indicators should use state of the art time calculation protocols such as those recommended with the `lubridate` package of the software R (R Core Team, 2016; Grolemund and Wickham, 2011).

Regardless of the time stamp format used, the resulting response time calculation will only be as accurate as the time stamps themselves. Even when initially set accurately, real clocks will differ after some amount of time due to clock drift or skew, caused by clocks counting time at slightly different rates. Thus, clock skew in a distributed system must realize the same global time. Clock or time synchronization is a central topic in computer science and engineering that aims to coordinate otherwise independent clocks (Cristian, 1989) especially in distributed systems (Lamport, 1978). The oldest protocol for time synchronization in a network is the Network Time Protocol (NTP) which has been under continual development and updating since 1979 (Mills et al., 2010). The NTP works based on a hierarchical, peer-to-peer structure of computers and servers organized into strata with the top level strata containing a set of high-precision reference clocks. In contrast, the Institute for Electrical and Electronics Engineers also specifies a time synchronization protocol for networked measurement and control systems. Specifically, the Precision Time Protocol, encapsulated in standard, IEEE 1588, operates using a master-slave framework with corrections for both clock offsets and network delays (IEEE, 2008). To ensure the integrity of time stamps within EMD systems, synchronizing all computers to the same clocks using the same synchronization protocols is a must.

The remainder of this paper uses a prototype EMD system to understand the extent of time synchronization related data corruption on response time data when only limited synchronization protocols are implemented.

3 CASE STUDY SYSTEM

To achieve time synchronization over the network, our case used the NTP. As a time source, the Global Positioning System (GPS) is used for central clock synchronization. Although GPS time signals are accurate, clock skew still introduces time stamp issues

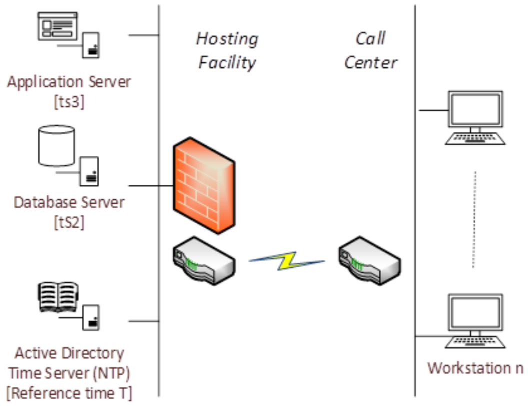

Figure 1: Overview of Case Study EMD.

into database records. The more computers involved in a system, the more likely that skew will be reflected in the data.

Specifically, in the emergency response system that we studied, the call center consists of a few (6-14) workstations taking calls and logging them into a system. The workstations at the call center are physically in a different location than the corresponding servers for data entry. The workstations and data entry servers are separated by a set of firewalls and connected via a Virtual Private Network (VPN), these two end points may incur delay in synchronizing their time. The system is depicted in Figure 1.

In order to follow the process of time stamping and its relationship to the process of time synchronization, Table 1 specifies the component, the time reference to which that component is synched, and a time stamp id associated with the component. As shown in Table 1, at regular intervals, the application and database servers set their clock to the reference time tS1 of the NTP Time Server. When a user/agent logs into a workstation session, the time stamp is reset to the Application Server time, thus at the workstation t = tS3. When opening a new call on the system, a key database record is created with a time stamp of tR1 which is equal to the database clock time at that instance, tS2. In this case, if the server clock is skewed when the record is created, but gets reset subsequently, then a timing error could be introduced. As the call progresses, all statuses and subsequent records are stamped with the workstation time tRn as it is the workstation that initiates the data entry request, tRn = t.

In the case study system, tRn could drift based on the internal workstation clock. If the workstation is not cycled at every shift, to synchronize its internal clock with the system, the absolute difference between tS3 and t will increase inducing errors in time measurements. For example, within 5 minutes a clock could drift 280 milliseconds. If the clock synchronization occurs on a 24 hour basis, then a total of 80 seconds of drift may occur between the system and workstation clock. As a result, time stamp errors arise. These errors could manifest themselves in “events happening in the past” (i.e. tRn $<$ tR1 = tS2) based on the inaccurate time stamp. Furthermore, due to the number of computers used in creating any one record the drift is not confined to that of one computer. As such, measuring and correcting drift from log files is an untenable task.

4 RESULTS

The system described in Section 3 was used to monitor the calls made to a nation-wide ambulance response service between 1 January 2016 and 30 June 2016. For each call a time stamp in yyyy-mm-ddThh:mm:ss+hh:mm format was recorded for the time the record was created (eg. call received), the time the mission was scheduled (eg. assigned to an ambulance), the time the ambulance departed, the time the ambulance arrived to the case, the time the ambulance departed the case, the time the ambulance arrived to the transport destination, the time the mission was deemed complete, and the time the ambulance was available for service again. For the purpose of this study, we are interested only in the first four time stamps as these are the time stamps required to calculate ambulance response time following the commonly used definitions of response time – divided into the three intervals: record created to scheduled; call scheduled to ambulance departure; and time from departure to arrival at the case.

Within the six month study period a total of 35,527 calls were recorded. In February, a data extraction error led to the rounding of the time data to exclude the seconds. As such, the data from February were excluded yielding a total of 29,606 records. Of these calls, any record with any of the first four time stamps missing was excluded. Of note is the fact that no records were missing an entry for the created on time stamp; 102 records were missing the mission scheduled time stamp; 1039 were missing the ambulance departure time stamp; and 4450 records were missing the arrival to case time stamp. Each of the three time stamp types with missing entries requires that the ambulance crew report the time back to the dispatch center; when the crew fails to report the time, then the entry is missing. Once the records with these missing entries were culled, the data set had 24,391 records that were considered useable for this study.

Within the 24,391 valid records, time synchro-

Table 1: Time Synchronization and Flow of Time Stamps in Case Study System.

Component	**Time Reference**	**Time Stamp**
NTP Server	Time Source (GPS)	tS1
Database Server	NTP Server	tS2
Application Server	NTP Server	tS3
Workstation Session Time Stamp	Application Server	t set to tS3; reset at login
Database Key Record Time Stamp	Database Server	tR1 = tS2 at initiation of the call; ie. when the user creates the record
Time Stamp of Remaining Records Related to the Initial Key Record	Workstation Time	tRn = t* based on workstation's current time

nization errors were identified on the basis of negative time progressions when moving logically through the data. For example, if the time stamp associated with the mission being scheduled was before the time stamp associated with the creation of the record, then the difference between these two time stamps would yield negative time. Negative time intervals were considered to be a function of time synchronization issues. Had these errors been ignored then the average response time would be incorrectly reduced. Alternatively, if the negative intervals were accommodated in absolute terms, the impact on the average response time would likely show an inconsistent bias.

Of the 24,391 records, the vast majority of negative time intervals (21,716 records) occurred relative to the mission scheduled and created on records; the scheduled to departure interval had only 442 time synchronization errors; and the departure to arrival on scene interval had 187 time synchronization errors. The percent of negative time interval records apportioned by time interval type can be seen in Table 2. While a time synchronization error rate of nearly 90% for the first interval of the response time period may seem shocking, it is logical as the created on time stamp is generated by the call center server while the remaining time stamps are generated on the workstation terminals. It is these ICT component links that are most prone to time synchronization issues.

Having identified the intervals with time synchronization issues, we turn to the magnitude of those errors. Table 3 provides a summary of the mean, standard deviation, minimum, maximum, and first through third quartiles for the time synchronization errors in seconds. The data exhibits an extreme range within all time intervals. The maximum value within the created to scheduled interval reflects an error of 24 hours. This is likely due to poor synchronization between computers at the moment of the change from standard time to daylight savings time. Despite the extreme tail within the distribution of time synchronization errors, 75% of all errors are less than 106, 70, and 70 seconds for the created to scheduled, scheduled to departure, and departure to arrival at case intervals, respectively.

Table 2: Percent of records with negative time intervals by time stamp type.

Time Interval	**Percent of Records with Negative Time**
Created to Scheduled	89.04
Scheduled to Departure	1.81
Departure to Arrival at Case	0.77
Time on Scene	0.57
Time to Destination	0.48
Time at Destination	0.39
Time from Mission Complete to Unit Available	1.05
Time from Unit Available to At Station	0.56

5 CONCLUSIONS

The issue of proper handling of time related data is significant in the management of an information system. The issue becomes even more significant when the time data is intended for use in time critical settings such as EMD services. This paper serves to highlight the potential magnitude of time synchronization errors within a prototype EMD system.

A straight forward solution to this issue has not yet been devised. Some initiatives have tackled algorithms that may reduce clock skew (Gusella and Zatti, 1989). Other methods impose requirements of minimal delays on the network and are not suitable for distributed VPN based environments (Rentel and Kunz, 2005). "Skewless" clock synchronization is still a favored research subject, but unfortunately without any real field implementations in the context of distributed networks (Mallada et al., 2015). To date, the usage of internet based time synchronization has prevailed (Sherman and Levine, 2016). Ultimately the daunting task of keeping track of the cause-effect relations

Table 3: Descriptive Statistics of Time Synchronization Errors in Seconds.

Time Interval	n	Mean	Std. Dev.	Min.	Q1	Median	Q3	Max.
Created to Scheduled	21,716	92	927	1	46	70	106	86102
Scheduled to Departure	442	586	5819	1	17	37	70	86400
Departure to Arrival at Case	187	646	3645	1	15	30	70	40534

Table 4: Summary of errors found in study – their sources and recommended solutions.

Source of Error	Error	Recommendation
Human	Inconsistent time formats	Time formats should be decided on prior to implementation and used consistently in both time stamping and data extraction scripts.
Human	Time rounding	Rounding of seconds should never be done in a time critical environment.
Human	Adherence to time synchronization protocols	Establish work checklists that ensure regular checking and synchronization of clocks.
Design	Large intervals between synchronization lead to significant clock drift	Time synchronization should be invoked every five minutes as opposed to every 24 hours.
Design	VPNs over long distances can introduce clock drift as a result of latency	Components of an EMD system should be co-located on a fast local network.
System	Misuse of time formats	Ensure that all computers are set to produce time stamps following standard protocols: yyyy-mm-ddThh:mm:ss+/-hh:mm
System	Mishandling of time changes due to inter-location differences, daylight savings time regulations, and leap years	Ensure that the offset from universal time is properly set and maintained across all system components.

among different data manipulations continues to occupy engineers and scientists who seek to develop a way to increase the accuracy of time tracking in distributed systems (Bravo et al., 2015).

At a minimum, a set of primary recommendations for EMD systems emerge from this research. A summary of the time related errors encountered in this research and the corresponding recommendations are listed in Table 4. These recommendations are critical as many response time targets are on the order of seconds, but time synchronization related problems can yield errors that are on the order of minutes.

This study is not without limitations. The time synchronization errors studied in this paper were found by identifying time intervals with "negative" time. Thus, the errors reported here potentially reflect only half of the errors actually present in the data. Unfortunately, it is impossible to identify time interval related errors when the intervals reflect a logical progression within time.

Furthermore, the results are based on a system for which limited time synchronization was performed in order to yield a worst case analysis scenario. Future work includes studying the same system after the recommendations noted in Table 4 have been adopted. Subsequent studies should also seek to sample from multiple dispatch systems in operation with different configurations in order to determine a realistic range of potential time related errors.

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