RTLS and the Built Environment

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The purpose of this paper is to discuss the value and limitations of Real Time Locating Systems (RTLS) to understand the impact of the built environment on worker productivity. RTLS data can be used for many other purposes (e.g. – equipment tracking[1], real time personnel finding[2], patient and guest finding[3], etc.) which are the basis for the cost justification of RTLS systems.[4] It seems intuitive that RTLS data can be useful in understanding the impact of the built environment on the caregiver's workload.[5] This paper will discuss the relevant factors, issues, and limitations for using RTLS data on workplace design and layout optimization projects.

By way of disclosure, RMC has developed software, called Layout-iQ[6] that models the impact of the built environment on care giver workload. Layout-iQ is used by Architects, and hospital designers to optimize the layout of the hospital. Data inputs for Layout-iQ include the sequence of trips that caregivers make during the workday, which can be derived from an RTLS data source. Layout-iQ has been designed to accept data derived from many sources including RTLS systems and RMC has an interest in validating RTLS systems for use with Layout-iQ. RMC has tested many RTLS technologies for use with Layout-iQ, including RFID, IR, WIFI, Ultrasound, UWB RFID, and combined IR and RFID systems.

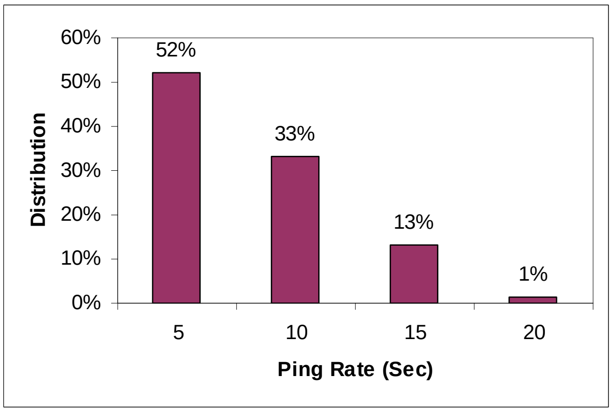
RTLS System Description

RTLS systems typically involve the placement of **detectors** around the built environment that are connected to a central computer on the hospital's network. Workers in the workspace wear **tags** that ping at a given frequency. When the tag pings, the detectors in the layout hear the ping and report the signal strength of the tag to the central computer on the network. The computer analyzes the incoming data from all of the detectors to determine the exact location of the tag in real time.[7] Every RTLS vendor has developed proprietary **software** algorithms that determine the location of the tag based on the strength of the signal from multiple detectors.

The rate at which the tag pings directly impacts the accuracy of the data. When human workers are wearing the tag the frequency of the ping should be 5 seconds or less to capture all the activities of the caregiver. Since many RTLS systems have ping rates of 20 seconds or greater, these systems require modifications to speed up the ping rate. When turning up the ping rate, it is important to carefully monitor the battery performance of the tag. Most RTLS vendors should give an estimate for battery life based on the ping rate of the tag. Many RTLS systems use Radio Frequencies (RF) that are regulated by the FCC which determines the maximum ping rate allowed for a given spectrum for tags worn by a human subject. While the allowable ping rate varies by spectrum, the maximum ping rate for tags placed on human subjects is commonly 20 seconds.

One method of overcoming a 20 second ping rate is to place multiple tags on the subject. In a recent lab test, we placed 4 tags with a 20 second ping rate on a dummy subject and measured the effective ping rate of all 4 tags combined. In our test, we found that the actual ping rate of each tag varied +/-10%, causing the effective ping rate of the 4 tags to converge resulting in significant time gaps in the ping rate. Figure 1 shows the distribution of pings with less than 5 seconds between pings; between 5 and 10 seconds between pings; between 10 and 15 seconds between pings; and greater than 15 seconds between pings. **Notice that 48% of the time the ping frequency exceeded the 5 second target.**

Figure 1. - (4) Tags Combined Ping Rate



Therefore, the strategy of using multiple tags to overcome longer ping rates is generally not recommended. The take away is that RTLS systems with tags that cannot meet the 5 second ping rate should not be considered as a data source in a Layout-iQ project.

All RTLS systems must be tuned or calibrated for accuracy prior to use.[8] The tuning process involves walking a tag around the unit, entering and exiting rooms and workspaces while reading the software's determination of tag location. If the software fails to recognize a location change when a tag enters a room, then the system administrator can change the sensitivity of the detectors in the algorithm to trigger the location change at the desired spot such as at the doorway. All RTLS systems should be re-calibrated frequently because the sensitivity of the detectors can change over time due to many factors. If the RTLS system is being used to collect data for a Layout-iQ study, then I recommend that the RTLS system be monitored and re-tuned if necessary at least 1 to 2 times per day to ensure accurate data. If the RTLS system is being used for equipment tracking only, then recalibration can occur once per month or as needed.

If the RTLS system already exists in the hospital, then an assessment needs to be done to ensure that each functional area/room of the layout has a unique detector installed.[9] Unfortunately, most hospitals don't pay enough attention to detector placement during the installation of the system and the result is that their RTLS data doesn't have the coverage necessary to do a thorough Layout-iQ study. The Time Study RN National Benchmarking Database (NBD) which contains data from more than 400 in-patient nursing units throughout North America includes the following functional areas that need detector coverage:

- Patient Rooms
- Patient Meds Storage
- Narcotic Storage
- Supply Storage
- Equipment Storage
- Nursing Stations
- Documentation Servers
- Kitchen
- Clean Storage
- Dirty Storage
- Conf Room
- Patient Bath
- Staff Toilet

Compatibility with the NBD is important if the hospital wants to benchmark with other similar hospitals in North America. Hospitals with existing RTLS systems may need to add detectors to the layout to ensure desired coverage. If a hospital is planning an RTLS system installation in the future, then serious consideration should be given to placing detectors in these locations for compatibility with the NBD.

RTLS Dataset Limitations

There are significant limitations that users need to be aware of when working with RTLS datasets.

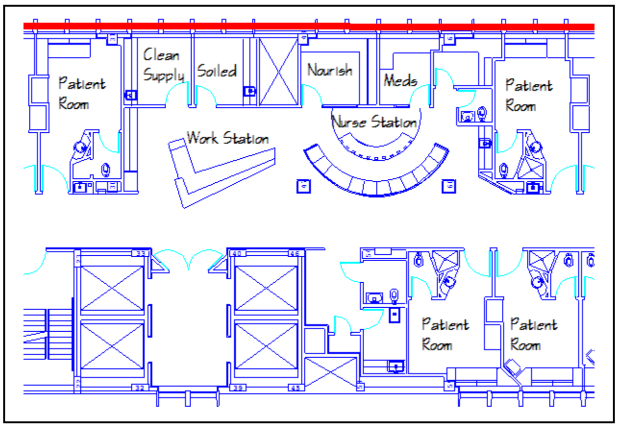
Missing Activity and Purpose Attributes

A significant limitation of an RTLS dataset is that there is no activity or purpose associated with the change of location record. Why was the caregiver there? What was the caregiver doing? It is extremely difficult to find and eliminate waste in workflows that are recorded in the RTLS record because there is no way to tell what the caregiver was doing at the time of the event. RTLS datasets capture all the inefficiencies that occur in workflow and without the ability to filter out those inefficient data the Layout-iQ model produces significantly less than optimal results because the new design will be optimized on the inefficient and wasteful processes captured in the RTLS dataset. By comparison, data collection by direct observation or using the Time Study RN PDA's solves this problem because activity and purpose attributes are recorded with the location change. Inefficiency and waste can be filtered out of the dataset ensuring that the new hospital design is optimized to enable value-added work and encourage optimal workflows.

RTLS Cannot Detect Chains

RTLS systems are not able to detect a chain of location change events. For example, let's consider a common in-patient unit design that requires the nurse to walk through the nursing station to access the meds room. In this scenario, the RTLS system would show a high relationship between the patient room and nurse station, and a high relationship between the nurse station and meds room and no relationship between the patient room and the meds room. Since an RTLS system has no way to detect the beginning and end points of a chain, this problem cannot be corrected in the dataset. An example of a unit design that causes these chains to occur in the RFID dataset is illustrated in Figure 2.

Figure 2: Layout causing Chains in Dataset.



By comparison, data collection by direct observation or using the Time Study RN PDA's solves this problem because the beginning and end points of the location change event are recorded ensuring that the correct relationships are captured.

High Rates of Missed Events and False Positives

RTLS datasets generally include a significantly high number of errors when compared with traditional data collection methods such as Direct Observation and Time Study RN. These errors can occur even when systems are properly tuned because of the complex dynamics taking place in the workplace.[10] For example, if a care giver is in the nursing station and another caregiver is standing in front of the detector in the nursing station blocking it; it's possible that a detector in another room such as the meds room could record a stronger signal strength than the detector in the Nursing Station. We call this type of error a "False Positive" because the system inserts a location change into the record that didn't happen. Another common cause of a "False Positive" record is when a care giver gets close to a boundary without actually crossing it and the system records the change of location event incorrectly.

The second type is error is called a "Missed Event" and this occurs when a caregiver changes locations and the system doesn't record it. This can happen frequently when a nurse is moving in and out of locations quickly. The rate of missed event errors increases directly in relationship with the ping rate of the tags. A ping rate of 5 seconds or less is desired because it ensures that the system captures change of location events with short durations, which occur frequently in nursing.

1 Error in RTLS Sequence Causes 3 Errors in Layout-iQ Dataset

One error in the RTLS sequence causes three errors in the Layout-iQ dataset. To demonstrate this concept lets assume that a Nurse travels from the "Nursing Station" to a "Meds Room" then to a "Patient Room" as illustrated in Figure 3. This sequence of 3 locations actually represents 2 relationships in the built environment that impact the nurses workload. Those relationships are a trip from the "Nursing Station" to the "Meds Room"; and a trip from the "Meds Room" to the "Patient Room". If the "Meds Room" is removed from the sequence as illustrated in Figure 3 - "RTLS Miss", then both

Figure 3. - Impact of RTLS Miss

Actual Sequence	**RTLS MISS**
1. Nursing Station	1. Nursing Station
⇩	⇩
2. Meds Room	
⇩	
3. Patient Room	3. Patient Room
Layout-iQ Dataset	**Layout-iQ Dataset**
1. From NS to Meds	1. NS to PR
2. From Meds to PR	

relationships in the Actual Sequence Layout-iQ dataset are now "Misses" and a new relationship is created between the "Nursing station" and the "Patient Room" which is a False Positive. Therefore, when a miss occurs in the RTLS data sequence, this causes 2 misses and 1 false positive in the Layout-iQ dataset.

When a false positive occurs in an RTLS sequence then the data will include 2 false positives and 1 miss in the Layout-iQ dataset. To demonstrate this concept lets take the sequence in the example above and insert a "Soiled Room" between "Meds Room" and "Patient Room" as illustrated in Figure 4. The new sequence now includes the nurse traveling from the "Meds Room" to the "Soiled Room" then to the "Patient Room". In this new sequence we lose the relationship between the "Meds Room" and the "Patient Room" which is a miss, and we now have two new relationships... one between the "Meds Room" and "Soiled Room" and another between "Soiled Room" and the "Patient Room" which are false positives. Therefore, a false positive in an RTLS sequence results in 2 false positives and 1 miss in the Layout-iQ dataset.

Figure 4. - Impact of RTLS False Positive

Actual Sequence	**RTLS MISS**
1. Meds Room	2. Meds Room
⇩	⇩
2. Patient Room	2(fp). Soiled
	⇩
	3. Patient Room
Layout-iQ Dataset	**Layout-iQ Dataset**
1. From Meds to PR	1. Meds to Soiled
	2. Soiled to PR

In order to achieve a research quality dataset of 5% error or less, the RTLS sequence error must be less than 2%. The most accurate RTLS dataset that I have measured in the field had 15% error in the sequence, which means that approximately 40% of the records in the Layout-iQ dataset are either misses or false positives. Many reliability tests on installed RTLS systems have been performed with error rates above 50%.

No Error Detection and Correction Contingency

Because RTLS is an automated system, there is no human present to find and correct the error once it has been recorded. By comparison, when data collection is done by either direct observation or with Time Study RN a correction can be made by the observer or participant immediately; therefore, data collected from these methods should be free of errors. However, when an error does occur in either of these two methods Time Study RN has an additional advantage because it records data in the Layout-iQ format, therefore, the error results in only 1 error in the Layout-iQ dataset. Because the direct observation method records location change sequences in the same way the RTLS system does, errors in the sequence also cause 3 errors in a Layout-iQ dataset.

RTLS Errors Impact the Shape of the Density Function More Aggressively

It's also important to understand the impact that errors have on the dataset. An important output of the data collection is a density function that represents the relevant probabilities of frequencies of trips caregivers make in their work day. This density function gives us the importance of the proximity of locations/features in the built environment. The shape of the density function is critical because it allows us to correctly prioritize the functional requirements in the layout. Another troublesome factor of RTLS datasets is that a high number of errors are usually caused by a few problematic detectors. There are many technical reasons for why certain detectors behave unreliably. For whatever reason, this is a common if not global problem that impacts the RTLS dataset by significantly changing the underlying probabilities and shape of the density function. By comparison, errors made in the Direct Observation or Time Study RN methods tend to be randomly distributed throughout the dataset, which means that they have less impact on the shape of the density function. The limitations of RTLS datasets discussed above as well as inadequate planning and execution of RTLS deployments help to explain why density functions derived from RTLS data generally look nothing like density functions derived from Direct Observation or Time Study RN datasets.

Methods for Testing and Validation

The most effective method to test the reliability of an RTLS system is to place multiple tags on a caregiver for a given time period and then analyze the output. Running this test for 1 hour can provide significant insight into the reliability of the system. Reliability is determined by verifying that each tag followed the same path with approximately the same entry and exit times.

Figure 5. - Reliability and Accuracy Test for RTLS system in an In-Patient Nursing Unit.

Observer with PDA				RTLS Location ID Sequence				
Enter Time Stamp	**Exit Time Stamp**	**Duration (sec)**	**Actual Location ID**	**Tag 68**	**Tag 69**	**Tag 70**	**Tag 71**	**2 Tag Rule**
11:1:18	11:3:43	145	17	17	17	17	17	17
11:3:47	11:4:59	72	31	31	(Miss)	(Miss)	31	31
11:5:3	11:5:4	1	17	(Miss)	(Miss)	(Miss)	(Miss)	(Miss)
11:5:35	11:6:46	71	16	16	16	16	16	16
					18 (FP)			
					16 (FP)			
					18 (FP)			
				47 (FP)	47 (FP)			47 (FP)
11:7:30	11:7:34	4	17	(Miss)	(Miss)	(Miss)	17	(Miss)
11:7:38	11:7:42	4	31	31	31	31	31	31
11:7:45	11:9:40	115	17	(Miss)	(Miss)	17	(Miss)	(Miss)
11:9:55	11:13:30	215	16	16	16	16	16	16
					15 (FP)			
11:13:41	11:13:55	14	17	17	17	17	17	17
11:14:10	11:16:13	123	16	16	16	16	16	16
11:19:10	11:21:7	117	17	17	17	17	17	17
11:21:10	11:21:17	7	31	(Miss)	(Miss)	(Miss)	31	(Miss)
11:21:20	11:21:22	2	17	(Miss)	(Miss)	(Miss)	(Miss)	(Miss)
11:21:25	11:21:29	4	30	(Miss)	(Miss)	(Miss)	(Miss)	(Miss)
					31 (FP)			
11:21:32	11:22:5	33	17	(Miss)	17	(Miss)	17	17
11:22:18	11:23:28	70	15	15	15	15	15	15
			Misses	7	7	7	4	6
			False Pos.	1	6	0	0	1
			% Error	50%	81%	44%	25%	44%

The accuracy of the system can be determined by adding an observer who follows the caregiver during the reliability test and records the exact entry and exit timestamp for each location change event. PDA's can be used by the observer to improve the accuracy of the timestamp and significantly reduce the observers workload during the observation period. The PDA's clock must be synchronized to within +/- 0.5 sec with the clock in the RTLS software. An example of a reliability and accuracy test result that was performed at a hospital using RTLS technology (e.g. - combined RFID and IR) is illustrated in Figure 5. This test was performed 1 hour after the system was calibrated by the vendor.

Notice the variation in the durations that occurred during the observed time period. It is absolutely critical when testing the reliability of an RTLS system to use actual caregivers working at their normal pace. Reliability studies with constant durations don't represent the dynamics of the environment sufficiently and should not be used to test the reliability an the RTLS system.

Conclusions

This white paper does not challenge the benefits and value propositions of using RTLS for equipment tracking and real time locating to improve operations. This paper only covers the limitations of using RTLS data to understand the impact of the built environment on caregiver workload. Instinct and intuition tell us that RTLS data can be used to understand more about how the built environment impacts caregiver productivity. Unfortunately many health systems have relied on this intuition, anticipating that their RTLS data can be used to create a more efficient hospital design.

While Layout-iQ supports RTLS datasets, given the limitations that have been identified and discussed in this paper, RTLS datasets are not recommended for use with Layout-iQ. Data collection by Direct Observation or Work Sampling using a system like Time Study RN is preferred because the datasets can include activity and purpose attributes, location chains are filtered, errors are detected and corrected as the data is collected, and the shape of the density function is less likely to change when an error occurs in the dataset.

International Standards for Real Time Location Systems (RTLS) can be accessed at the International Organization for Standardization website.[11] To learn more about RTLS, the author strongly recommends the book "RTLS for Dummies" by Ajay Malik.[12]

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[1] Cost saving, real time location solutions (RTLS) for healthcare, Skytron, Executive Healthcare, 10 December 2010, Available [Online] http://www.executivehm.com/article/Cost-saving-real-time-location-solutions-RTLS-for-healthcare/

[2] Real Time Location Systems, A White Paper from Nanotron Technologies GmbH version 1.02, 30 May 2007 Available [Online] http://nanotron.com/EN/pdf/WP_RTLS.pdf

[3] RFID Technology from Texas Instruments and RF Code Brings Service and Safety to Guests at Steamboat Ski Resort, Press Release - 5 April 2005, Available [Online] http://www.rfidjournalevents.com/live2005/press_releases/RF%20Code.pdf

[4] Early RTLS Adopters Report Success with Initiatives, Steve Van Wagenen, KLAS, Healthcare IT News, September 2009. Available [Online] http://www.medtechpublishing.com/rtls/RTLS.pdf.

[5] Considering a Real-time Location System? First Consider the 5 Critical Success Factors, Jason Howe, Aware Point White Paper, 2008 Available [Online] http://www.awarepoint.com/documents/Awarepoint_5factors.pdf

[6] Layout-iQ: Workspace Planning Made Easy, Nelson E. Lee, Rapid Modeling Corporation Website, Available [Online] http://www.Layout-iQ.com/

[7] Real Time Location Systems, Clarinox Technologies Pty Ltd., November 200, Available [Online] http://www.clarinox.com/docs/whitepapers/RealTime_main.pdf.

[8] Estimating Location Sensor Deployment Unrealistically, RTLS for Dummies, pg 254, Ajay Malik, Wiley Publishing Inc., 2009

[9] Real-time Location Systems (RTLS) in Healthcare: Wi-Not Wi-Fi?, Whitepaper - Integra Systems, David H. Hoglund, 2009, Available [Online] http://www.integrasystems.org/main/images/stories/Whitepapers/Wi-NotWi-Fi.pdf

[10] Real-Time Error in Location Modeling for Ubiquitous Computing, Jeffrey Hightower and Gaetano Borriello, 3 Oct 2001, Available [Online] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.25.4262&rep=rep1&type=pdf

[11] International Organization of Standardization Website, http://www.iso.org/iso/search.htm?qt=rtls&sort=rel&type=simple&published=on

[12] RTLS for Dummies, Ajay Malik, Wiley Publishing Inc., 2009 Available