AN APPROACH TO RTLS SELECTION

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Abstract
Real Time Locating System has become an important part of supporting technologies applied in a wide range of logistics related to many sectors and branches, as warehousing, manufacturing or healthcare offering real time visibility of assets. It increases assets utilization. RTLS is a very wide term covering many different specific technologies. The use of a specific technology effects in achieving different performance metrics. Therefore, the selection of a specific technology (or mix) is multi-criteria decision making problem. A set of criteria for RTLS selection was discussed and confronted with a set of criteria for assessment of identification systems and an application of TOPSIS for the selection of RTLS was presented.

Keywords:
Real Time Locating System (RTLS), Radio Frequency Identification (RFID), multi-criteria decision making (MCDM), group Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

1 INTRODUCTION
According to ISO standards
Real Time Locating Systems (RTLS) "are wireless systems with the ability to locate the position of an item anywhere in a defined space (local/campus, wide area/regional, global) at a point in time that is, or is close to, real time. Position is derived by measurements of the physical properties of the radio link.” [1] Above definition reflects RTLS as a specific use of radio frequencies, to achieve location data. However, systems employing other technologies, like infrared light (IR), ultrasound (US), and hybrid solutions (IR-RF, US-RF, IR-US-RF) exist. IR and US allows to eliminate some shortages of radio e.g. radio penetrates walls, therefore to precisely distinguish locations between adjacent rooms, US could be applied. RTLS characteristics depend on specific technology being involved. Therefore, the selection of the RTLS is a multi-criteria decision making problem, which includes both qualitative and quantitative criteria. Ultra-Wide Band (UWB), Radio Frequency Identification (RFID), Wi-Fi, ZigBee (based on IEEE 802.15.4), Bluetooth (BT) and Infrared (IR) are commonly used RTLS technologies [2]. However, the list is not extensive, nor systematic. For the purpose of this paper, Radio Frequency Identification is each technology using radio frequencies to identify and eventually locate a tagged object. Therefore, RTLS could be treated as a specific use of a broader Radio Frequency Identification (RFID) group of technologies, that sometimes is hybrid of RFID and other technologies. An attempt to the typology of RFID systems including RTLS was presented by Gladysz [3]. Practically, when production and logistics shop-floor, middle and top managers talk about RTLS they have in mind a kind of indoor positioning system, that could be called colloquially “an indoor GPS”. Therefore, the definition of RTLS is focused on the goal of the system (locating objects), rather than on standards and technologies applied. For the purpose of this paper, the RTLS is always used in relation to the process of locating objects in relative coordinates.

Detailed infrastructure may differ depending on a specific technology (see Figure 1a). RTLS general infrastructure consists of four main components (see Figure 1b). Tags are attached to and identify objects being located. Locating devices are fixed in space and communicate wirelessly with tags, and location engine. Location engine, is a software calculating positions of tags on a basis of data from locating devices. User applications and interfaces are necessary to integrate RTLS with backend systems.

2 APPLICATIONS OF RTLS
Applications of RTLS are almost unlimited. Anytime an organization strives lack of real time data on a position of its assets, RTLS may offer a solution. There is a broad literature on RTLS applications within healthcare [4], warehousing and manufacturing. A comparison of RTLS technologies reflecting needs of healthcare was presented by Asosheh and Khanifar [5], but presented parameters are valid not only for healthcare. An updated comparison, excluding hybrid solutions, is presented in Table 1. However, it is general comparison and should serve only as a signpost. RTLS applications in warehousing, manufacturing and logistics include, but are not limited to controlling and reducing inventory through smoothing information handling [6], cooperating within supply chain [7], fighting maritime piracy [8], assets tracking in container terminals [9], improving mobile (transportation) assets utilization in manufacturing [10], assets tracking on a shop floor [11]. Very wide spread of possible RTLS technologies and possible RTLS applications lead to the question: how to choose the best system for the purpose of a specific case. ScienceDirect, SCOPUS, and Web of Science databases were systematically queried (title, keywords, and abstract) for the following query: (“decision making” OR “selection”) AND (“RTLS” OR “Real Time Locati* System*”). In total, 40 journal and conference papers were screened. Papers related to strictly technological and mathematical issues like locating algorithms were not analyzed. Budak and Ustundag [2] presented the structure of decision making model for selection of RTLS, indicating a goal, two-level hierarchy of criteria (see Table 3), and alternatives. Similar study in healthcare was conducted by Asosheh and Khanifar [5]. A case study was presented as well, but different criteria were used. Optimal reader placement for asset tracking was discussed in [12]. Several authors discussed RTLS support for decision making systems and improvements in maintenance [13], construction consistency checking and component tracking [14,15], collision avoidance [16], offshore logistics [17]. Massive number of papers were related to healthcare application i.e. mobile assets sharing [18], workflow modeling [19], evaluation of different technologies [20], typology of RFID-based RTLS [21], inpatient care systems [22].
Table 1. Comparison of RTLS technologies.

| Parameter                                      | US | UHF | BT | LF | UWB | Wi-Fi | IR | GPS |
|------------------------------------------------|----|-----|----|----|-----|-------|----|-----|
| Coverage area of singular locating node [m]    | 30 | 15  | 10 | 2  | 30  | 50    | 0.5| Outdoor |
| Accuracy [m]                                   | 0.3*| 0.2*| 3  | 2-7| 0.2*| 2     | 0.5*| 15 |
| Room level usefulness [%]                      | 100 | 50  | 50 | 40 | 60  | 50    | 80 | 0 |
| RF interference potential                      | No | H   | M/H| M | No  | H     | L  | L |
| Bit rate                                       | L  | M   | M/M| VH| H   | L/M   | L  | H |
| Complexity                                     | L  | L   | M  | M | VH  | H     | L  | H |
| Initial cost                                   | L  | M   | M/M| M/H| H   | M/H   | M  | M |
| Security and privacy                           | VH | M   | M/M| M/H| M   | M/H   | M  | M |
| Health concern                                 | VL | M   | M/M| M/H| M   | M/H   | M  | M |

Legend: VL – very low; L – low; M- medium; H – high, VH – very high, * for the chokepoint detection use case

No papers were found regarding selection of RTLS in industrial environment (warehousing, manufacturing, etc.). Therefore, the main goal of this paper is to present and verify a methodology for selection of RTLS in industrial environment.

3 METHODOLOGY

The methodology of RTLS assessment and selection follows 6 steps (see Figure 2):

1. Definition of needs for RTLS.
   It must be defined what are boundaries of acceptable parameters in terms of cost/benefits, accuracy, reliability etc. This steps includes business case definition, so the most important question is: what RTLS will be used for.

2. Analysis of RTLS market.
   It must be discovered, if it is possible to fully satisfy defined needs with existing solutions. It not, what is the gap between state-of-art solutions and needs. Is it possible to fill this gap with turnkey solutions from RTLS providers and/or with own R&D, or not.

3. Synthesis of previous steps.
   Which is necessary to define possible alternatives, that will be assessed.

4. Settlement of weights for criteria.
   For this purpose, the set of criteria consisted of three subgroups (financial, implementation, technical) was proposed by Budak and Unstundag [2]. That set was discussed with experts involved in a survey and it was adopted, because it was evaluated as satisfactory.

Figure 2. Methodology of RTLS assessment and selection.
5. Weighting criteria. For the purpose of presented research, weights proposed by Budak and Ustundag [2] were adopted, where group and fuzzy AHP (Analytic Hierarchy Process) [23] was applied to evaluate the priority measure of criteria considering financial, implementation and technical dimensions. Weights were discussed and accepted by all experts involved in a survey.

6. Ranking of alternatives. TOPSIS [24] is applied to overcome the ranking problem. TOPSIS was developed to assess the alternatives, considering how far each alternative is from the ideal and negative ideal solutions, and selecting the closest, relative to the ideal solution as the best alternative. TOPSIS treats decision problem as geometric space within dimensions, where $n$ is the number of criteria. Alternatives are represented as points in the space. TOPSIS assumes that the best alternative is the one that simultaneously has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The ideal positive solution is a hypothetical alternative that has the best values for all considered criteria, whereas the negative ideal solution is a hypothetical alternative that has the worst values for all criteria. Positive criteria are those that should be maximized, and negative criteria are those that should be minimized.

4 VERIFICATION OF AN APPROACH
4.1 Definition of needs
Presented case is based on a cold chain warehouse. Cold chain is a type of supply chain where temperature must be controlled and preserved at a constant level. Cold chain logistics is focused on all areas of conventional logistics and additional issues related to the control of a temperature. Objects that are going to be monitored are forklifts within a warehouse. Company utilizes lean tools to improve its processes. Main features of considered RTLS implementation are four-fold:
1. a diagnosis tool to support lean initiatives by elimination of unnecessary movement and transport, so-called spaghetti diagram,
2. a controlling tool for a real-time monitoring of forklift routes and support for planning picking operations, loading/unloading operations based on integration with Warehouse and Transport Management Systems,
3. a controlling tool for a real-time monitoring of temperature by integration with wireless sensors on trucks,
4. a controlling tool for calculation of key performance indicators of forklifts (average speed, overall equipment efficiency among others).

Considering features presented above, two main requirements are precision of at least 0.5 m and flexibility in terms of integration with existing software solutions. The warehouse is operating, so RTLS implementation should be possibly non-interrupting warehousing processes. RTLS infrastructure should allow for easy dismantling and installation in other warehouses, as the idea is to circulate it between locations.

4.2 Alternatives
Three alternative solutions were considered (see Figure 3):
1. passive UHF (called later UHF pRTLS),
2. active Wi-Fi (called later Wi-Fi aRTLS),
3. active UWB (called later UWB aRTLS).

UHF pRTLS is based on relatively cheap tags (low investment cost). Passive tags do not require battery. UHF system operates in range 865 to 868 MHz allowed in EU. Therefore, they are easier and cheaper in maintenance. However, UHF pRTLS needs installation of relatively large amount of antennas, cabling, and additional hardware, what is increasing deployment and maintenance costs.

Wi-Fi aRTLS is based on Wi-Fi infrastructure and Wi-Fi enabled mobile devices. Wi-Fi routers serve as location nodes and mobile devices with Wi-Fi feature serve as tags. Big advantage of Wi-Fi solutions is its compatibility with commonly used Wi-Fi wireless communication networks. Wi-Fi tags are relatively expensive. Location nodes need both power cabling and network cabling. Tags must be supplied with its own source of power. Considered Wi-Fi aRTLS supports 802.11 b/g networks, so it operates 2.4-2.483 GHz, allowed in EU. Battery life is not critical, as tags are supplied directly from forklift battery.

UWB aRTLS is based on ultra-wide bandwidth and is not interfering with other radio systems. It operates in 3.5 to 6.8 GHz range of radio frequencies. Considered system requires only power cabling for location nodes. Network cabling is not necessary as location nodes form mesh network. UWB tags are relatively expensive, but can operate in two modes: tag and location node. Tags require own source of power, but power consumption is relatively low, if comparing to Wi-Fi tags. Battery life is not critical, as tags are supplied directly from forklift battery. In case of lack of power from forklift battery, UWB aRTLS tags could work longer, than Wi-Fi aRTLS tags.

4.3 Criteria
Criteria and their weights were proposed by Budak and Ustundag [2]. Other set of criteria was identified by Asosheh and Khanifar [5]. Those two sets were confronted and the one better fitting considered warehousing case was chosen. RTLS could be analyzed as a kind of identification system with extend feature of locating identified objects. Therefore proposed set of criteria was confronted with assessment criteria for identification systems. Shannon and Weaver [25] in their classical model of communication listed following problems of communication: (1) technical – how precisely communication symbols could be transferred, (2) semantics – how precisely (accurately) symbols could transfer desirable meaning, (3) effectiveness – how effectively received message lead to desired action.

Resulting risks are:
1. message is designed improperly,
2. message is encoded incorrectly,
3. message is distorted in communications channel,
4. message is not sent,
5. message is not transferred,
6. message is not received,
7. message is decoded incorrectly,
8. message is interpreted incorrectly.

Considering problems and risks in the communication process, identification system should be assessed including criteria described in Table 2. Chosen set of criteria, proposed by Budak and Ustundag [2], should relate to criteria given in Table 2. Relations are presented on Figure 4. All objects’ identification criteria are represented. Therefore the set proposed by Budak and Ustundag [2], that addresses all objects’ identification criteria and additional, RTLS-specific criteria, was adopted without changes. Final list of criteria with descriptions and weights is given in Table 3.
Table 2. Criteria for assessment of objects’ identification system.

| Criteria                  | Sub-criteria                  | Questions                                                                                                                                 |
|---------------------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Identification activities  | Speed                         | What are cycle times of identification activities? How identification activities impact lead time?                                       |
|                           | Reliability                   | What is the risk that object would not be identified or identified incorrectly? What is the risk that a system would be disturbed by its environment? (dirt, dust, electromagnetic fields etc.) What is the risk that data carrier or identification devices would be damaged? |
| Scope of a system         |                               | Are all desired objects being identified with a system? Are objects identified in all desired points in processes? Is the system integrated with all systems, that could benefit from data about identified objects? |
| Data                      | Quality of a structure        | Are all necessary data about identified object accessible? Are there redundant/unnecessary data in a message? Is a message understood for each stakeholder? What is the risk that a message would be decoded or interpreted incorrectly? |
|                           | Speed of a transfer           | What is the delay in message transfer? How messages are transferred? Are data accessible when schedules are being made? Is just in time rule enabled? |
|                           | Quality of a transfer         | What is the that data would be lost? What is the risk that data would be distorted while encoding, transferring or decoding? What is the risk that a message would not be sent, transferred or received? |
| Cost                      |                               | What is the cost of an investment? What is the cost of an operation? What is the cost of a maintenance?                                 |

4.4 Ranking

Decision problem (RTLS selection) consists of three alternatives (see section 4.2) and two-level hierarchy of criteria (see section 4.3). Three experts were involved to obtain assessment of three defined alternative RTLS solutions. For the purpose of the assessment a quantified on the linguistic “one-to-nine” measurement scale was applied, where 1 is extremely low evaluation, 2 – very low, 3 – low, 4 – moderate, 5 – average, 6 – strong, 7 – high, 8 – very high, 9 – extremely high. Final results of group TOPSIS are given Table 4. The solution, which is preferred according to executed TOPSIS procedure, is the one with highest value of relative closeness (RC). UWB aRTLS with \( RC = 0.77 \) was chosen as the preferable of
analyzed alternatives. It is significantly preferred over Wi-Fi aRTLS and extremely preferred over UHF pRTLS.

4.5 Sensitivity analysis
Sensitivity analysis was performed to check if the ranking is highly sensitive to small changes in the criteria weights.

Nine scenarios were prepared (see Table 5), because three incremental rates of each criteria group were analyzed, as suggested by Budak and Ustundag [2]. Results are presented in Table 6. Ranking is stable. UWB aRTLS has always the highest RC value.

Table 3. Criteria descriptions and weights (based on [2]).

| Criteria                  | Weights | Description                                      |
|---------------------------|---------|--------------------------------------------------|
| Cost                      | Financial 0.235 | Total cost of ownership |
| ROI                       | 0.500   | Return on investment                             |
| Implementation time       | Implementation 0.034 | Project duration with respect to roll-out |
| Organizational learning   | 0.420   | Adaptableability of employees to the RTLS enabled processes |
| Experience                | 0.206   | Need for restructuring business processes        |
| Process re-engineering    | 0.017   | Levels of technological experience by different implementation levels of RTLS |
| Usability                 | 0.050   | Ease of use and learnability of different RTLS   |
| Accuracy                  | Technical 0.029 | Locating precision |
| Response time             | 0.080   | Latencies in a system                            |
| Upgradability             | 0.005   | Openness and ease to upgrade                     |
| Maintainability           | 0.005   | Ease of internal and external maintenance        |
| Compatibility             | 0.008   | Integration with existing systems, ease of technological conversion |
| Security                  | 0.007   | Exposure for threats                             |
| Reliability               | 0.017   | Malfunction ratio                                |

Table 4. Ranking of RTLS alternatives.

| Alternative          | UHF pRTLS | Wi-Fi aRTLS | UWB aRTLS |
|----------------------|-----------|-------------|-----------|
| Relative closeness RCi| 0.256     | 0.537       | 0.770     |
| Rank                 | 3         | 2           | 1         |

Table 5. Scenarios of sensitivity analysis – criteria weights.

| Incremental rate of:          | financial criteria | implementation criteria | technical criteria |
|-------------------------------|--------------------|-------------------------|--------------------|
|                               | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      |
| Cost                          | 0.282  | 0.329  | 0.376  | 0.188  | 0.165  | 0.146  | 0.221  | 0.212  | 0.197  |
| Return on investment          | 0.318  | 0.371  | 0.424  | 0.212  | 0.186  | 0.164  | 0.249  | 0.239  | 0.223  |
| Implementation time           | 0.026  | 0.020  | 0.012  | 0.042  | 0.048  | 0.052  | 0.030  | 0.028  | 0.026  |
| Organizational learning       | 0.089  | 0.068  | 0.042  | 0.143  | 0.162  | 0.176  | 0.103  | 0.095  | 0.089  |
| Process re-engineering        | 0.162  | 0.123  | 0.076  | 0.260  | 0.294  | 0.319  | 0.186  | 0.172  | 0.162  |
| Experience about technology   | 0.013  | 0.010  | 0.006  | 0.021  | 0.024  | 0.026  | 0.015  | 0.014  | 0.013  |
| Usability                     | 0.040  | 0.030  | 0.019  | 0.064  | 0.072  | 0.078  | 0.046  | 0.042  | 0.040  |
| Accuracy                      | 0.025  | 0.018  | 0.016  | 0.025  | 0.018  | 0.014  | 0.054  | 0.072  | 0.090  |
| Response time                 | 0.009  | 0.006  | 0.006  | 0.009  | 0.006  | 0.005  | 0.019  | 0.025  | 0.031  |
| Upgradability                 | 0.004  | 0.003  | 0.003  | 0.004  | 0.003  | 0.002  | 0.009  | 0.012  | 0.015  |
| Maintainability               | 0.004  | 0.003  | 0.003  | 0.004  | 0.003  | 0.002  | 0.009  | 0.012  | 0.015  |
| Compatibility                 | 0.007  | 0.005  | 0.005  | 0.007  | 0.005  | 0.004  | 0.015  | 0.020  | 0.025  |
| Security                      | 0.006  | 0.004  | 0.004  | 0.006  | 0.004  | 0.003  | 0.013  | 0.017  | 0.022  |
| Reliability                   | 0.014  | 0.010  | 0.009  | 0.014  | 0.010  | 0.008  | 0.031  | 0.041  | 0.052  |

Table 6. Results of sensitivity analysis.

| RC value for scenario: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|------------------------|---|---|---|---|---|---|---|---|---|
| UHF pRTLS (A1)         | 0.218 | 0.191 | 0.168 | 0.313 | 0.353 | 0.386 | 0.250 | 0.244 | 0.242 |
| Wi-Fi aRTLS (A2)       | 0.553 | 0.563 | 0.568 | 0.507 | 0.484 | 0.462 | 0.532 | 0.526 | 0.516 |
| UWB aRTLS (A3)         | 0.811 | 0.839 | 0.860 | 0.706 | 0.661 | 0.625 | 0.779 | 0.787 | 0.792 |

5 CONCLUSIONS
The methodology enables relatively quick decision process at the early phases of RTLS implementation. The result is the ranking of possible RTLS solutions. An alternative with highest rank, should be analyzed deeper and has priority over other alternatives.
Proposed approach has some limitations to overcome in further research. Benefits of RTLS implementation were not addressed directly. The methodology is focused on selection of RTLS. The question, if RTLS is needed and how it can contribute to strategic advantage of a company, should be answered first. Such question could be answered using technology portfolio approaches. Criteria should be discussed deeper. The list of criteria is long and some of criteria have relatively low weights. Research could be designed to cumulate some criteria. Experts expressions were assumed to be equally weighted, what could be not true, if their level of experience differs. This could be eliminated by assigning weights to experts e.g. using AHP method. In further research linguistics scales would be used for qualitative expert evaluation, as alternatives are uncertain and human thoughts are fuzzy. Fuzzy sets would be applied as representation of linguistic scales.

Therefore, further research plan is four-fold: (1) analysis of criteria set, (2) analysis of experts expressions and eventually application of experts’ weighting, (3) application of fuzzy sets, (4) investigation of benefits and RTLS relations with lean objectives.

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