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Indicator-based Potential Analysis for Asset Tracking Applications

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Summary: The increasing adoption of advanced technologies such as wireless sensor networks and real-time location systems has significantly impacted asset tracking applications in industry and logistics. These technologies enhance the tracking and monitoring of assets, offering a new paradigm in factory automation by replacing traditional methods like labels and barcodes. Despite the clear benefits, the diverse range of technological solutions available necessitates expert knowledge to identify optimal systems for specific applications. However, the scarcity and commercial biases of such experts present challenges. This article aims to support companies in the decision-making process by presenting an indicator-based potential analysis methodology tailored for asset tracking applications. The methodology was developed through a comprehensive literature review and expert validation via a delphy study. The study identified and refined a set of indicators to accurately describe and compare asset tracking use cases. The results demonstrate a high level of agreement among experts regarding the relevance and attributes of the indicators. The validated indicators enable the quantification of the potential of various asset tracking applications, providing a structured approach to determine sub-potentials and overall application potential.

Keywords: Asset tracking, Wireless sensor networks, Potential analysis, Real time location systems.

1. Introduction

The potential of asset tracking applications in industry and logistic have become a significant focus of research due the increasing adoption of advanced technologies such as wireless sensor networks and real time location systems [1]. These technologies offer the capability to enhance the tracking and monitoring of assets in manufacturing and logistic. The implementation of wireless sensor networks represents a new paradigm for asset tracking in factory automation and these technologies are increasingly replacing labels and barcodes [2]. Furthermore, real time location systems have demonstrated the potential to support transparency, reuse and recycling and efficiency in industry [3-5].

On the other hand, a thorough understanding of the potential of the used technologies is essential for the development of effective strategies for asset tracking in industrial settings. Due to the huge variety of technological solutions tailored to specific applications, the expertise of specialists in this field is required to identify optimal solutions. However, such experts are often difficult to find and frequently have vested sales interests. Therefore, the aim of this article is to assist companies in the decision-making process for selecting the most suitable asset tracking system for specific use cases and quantify the possible potential of different applications.

2. Related Work

Schönmann et al. developed a methodology for the planning and evaluation of production technologies [6]. Steinwender presented a model for the multicriteria potential analysis of additive manufacturing [7]. The critical reflection of these approaches reveals that they are very helpful for decision making, but there are no comprehensive methodologies for the potential of asset tracking technologies. This necessitates the adaptation and further development of existing approaches to create a suitable methodology for the specific field of application.

3. Method

This article describes an indicator-based potential analysis of asset tracking applications in industrial environments. Indicators are a specific type of metric used to represent complex, uncertain, or empirically unsubstantiated relationships [8] and are suitable for the use with imprecise information and for early detection of potentials [9].

The first step was to carry out a literature recherche that defines indicators, that describe asset tracking applications in general. Subsequently, these indicators were evaluated in terms of specificity, assess ability, redundancy, clarity and relevance, as described by Probst and Gomez [10]. After defining a set of indicators a delphy study was conducted with experts from industry und science to validate the found indicators and find correlation between indicators and the potential for asset tracking applications. This data can be used to calculate the potential of various use cases for asset tracking and can help companies in technology management to find the ideal use case.

4. Results

To capture indicators, parts of existing models can be adapted, but after an intensive literature recherche no models for asset tracking applications were found. Thus, initial requirements were derived from expert interviews and a thorough literature review, primarily using review articles on asset tracking. This process identified 30 preliminary indicators, which were evaluated in focus groups, reducing the list to 25 by eliminating five. These remaining indicators were analyzed for interdependencies and redundancies using Probst and Gomez's influence analysis [10], resulting in a final set of 16 indicators. This set enables a clear description and comparability of asset tracking use cases and describes a use case on four different levels: asset, environment, transponder, and IT system, as shown in Fig. 1.

Indicators for Asset Tracking Application

Asset	Enviroment	Transponder	IT System
amount of assets	installation effort	costs for transponder	interoperability
asset size	influence enviroment	additional sensors	location accuracy
value of an asset	monitored area	transponder design	time resolution
asset system level		power supply	data privacy
required information			

Fig. 1. List of indicators for asset tracking applications.

The following section briefly describes the indicators found and defines their influence on asset tracking use cases:

Asset Indicators – these metrics provide essential information about assets within a system, influencing asset management and strategic planning:

- **Number of assets** is crucial in determining the efficiency and scalability of tracking systems. An increased number of assets requires more robust infrastructure and increase implementation and maintenance costs, impacting system design and scalability considerations [11, 12];
- **Asset value** is critical for prioritization and security measures in asset management. High-value assets necessitate more robust tracking systems, influencing resource allocation and the choice of technologies [13];
- **Asset size –** affects tracking technology choices. Small assets are suited for passive RFID, while larger assets can accommodate active transponders with higher energy demands. Larger assets may also justify costlier systems due to increased risk [14, 15];
- **System level** influences the choice of transponders and the resolution of tracking data. Higher-level assets typically require active tracking technologies for more precise monitoring [16];
- **Asset information** specific to each asset, such as serial numbers and maintenance history, is critical for ensuring secure processes and selecting appropriate transponders with adequate storage [14, 17].

Context Indicators – these indicators provide insights into the operational context of tracking systems, essential for effective implementation and integration:

- **Area size** significantly impacts system effectiveness, requiring more resources and infrastructure for larger areas, and influences the choice of localization technologies [18];
- **Installation effort** varies by technology and environment. Autonomous transponders offer low installation complexity but may lack data processing capabilities. Temporary systems require careful consideration of installation ease [19];
- **Environmental influence** Successful deployment of identification and localization technologies depends on understanding their capabilities and risks in the existing environment. Inadequate knowledge can lead to inefficiencies and system failures [12].

Transponder Indicators: Key aspects such as form factor, cost, and power supply determine the suitability of transponders for various environments:

- **Form factor** impacts system efficiency, reliability, and integration. It also affects energy efficiency, especially for battery-powered sensors [20, 21];
- **Cost of a transponder** is crucial for large-scale deployments, influencing project profitability. Cost-effective sensors must not compromise system performance [15, 22];
- **Power supply** is vital for transponder longevity and reliability. Energy-efficient solutions, such as passive RFID, are essential for large-scale systems to minimize maintenance [13, 23];
- **Sensor integration:** Additional sensors enhance provide environmental data but increase system complexity, particularly in Bluetooth-based setups [24, 25].

IT System Indicators include location and time resolution, data privacy, and interoperability, which are crucial for evaluating the performance and effectiveness of tracking systems:

- **Time resolution –** higher time resolution, for example ‘position-update every day’ decreases data transmission intervals, reduces energy consumption and extends transponder battery life but may impact real-time tracking accuracy [26];
- **Location Accuracy –** higher location accuracy improves tracking precision but can increase complexity and costs, requiring careful consideration during system design [14, 21];
- **Data privacy** ensuring data privacy is critical to protect corporate information and employee rights, requiring a hybrid approach of design and policy-based solutions [25, 26];
- **Interoperability** enables seamless integration across different systems, enhancing efficiency in logistics and transport. However, in less digitized environments, isolated solutions may suffice [16, 22].

The potential analysis to be developed for asset tracking use cases should also be feasible for employees without specific track & trace knowledge. It is therefore crucial that the indicators themselves are assigned explanatory attributes. These attributes of the various indicators were defined in focus groups and experts and system manufacturers. An overview of all the attributes of the use case indicators is available on github.com.

The 'amount of asset' and 'time resolution' indicators are presented as examples in this article. This provides an overview of how the various attributes of the indicators can be used for potential assessment.

The 'amount of asset' indicator describes the number of assets to be monitored in the use case. There are various threshold values above which certain technologies can no longer be used economically or a very low number opens up different technology choices. For example, with more than 1,000 assets, only RFID can be used economically, as this passive technology is easier to maintain than systems where transponders require an active power supply.

For up to 100 assets, technologies such as Bluetooth, UWB and GPS are also suitable, as it is still possible to charge or replace batteries with manageable effort.

The IT-system indicator 'time resolution' performs in a similar way. It indicates how high the required position update rate of assets in the system should be. High update rates result in higher energy consumption and therefore shorter battery life for the transponders. However, if the transport route has to be traced in detail, a high update rate (position update at least every second) is necessary. If it is sufficient to update the position once a day (position update daily), the potential of the application is of course lower, but may be sufficient for specific applications.

Table 1 shows the attributes and the corresponding values of the "amount of assets" and "time resolution" indicators.

Table 1. example for attributes of the indicators 'amount of assets' and 'time resolution'.

amount of assets	
attribute	**impact**
more than 1000 assets	0.944
101 - 1000 assets	0.833
51 - 100 assets	0.611
6 - 50 assets	0.556
1 - 5 assets	0.313

time resolution	
attribute	**impact**
position-update every second	0.833
position-update every minute	0.750
position-update every hour	0.722
position-update every day	0.500
position-update if moving	0.417

To validate these results, a Delphi study was conducted with experts from both industry and academia. The study aimed to assess the suitability of the indicators for clearly describing asset tracking use cases, as well as the significance of each indicator's attributes concerning the overall potential upon implementation.

The study involved eleven experts and was conducted in May 2023. Special attention was given to selecting specialists with extensive experience in the field of Track & Trace. Table 2 shows the job positions of the participants. The study was conducted online, and after the first round, the evaluations of the entire group were sent to each participant, with a request to adjust their responses if necessary. First the participants were asked, if a specific indicator is relevant to the potential of an asset tracking application.

Table 2. Participants of the delphy study.

ID	Position
Participant 1	Product Manager RFID
Participant 2	CEO Track & Trace Software
Participant 3	Director of Product Management Track & Trace
Participant 4	Innovation consultant
Participant 5	Head of data and processes
Participant 6	Professor for supply chain management
Participant 7	CEO Track & Trace Hardware
Participant 8	Head of R&D for Logistics
Participant 9	Head of research Group for Logistic
Participant 1(	Head of Institute for Industrie 4.0
Participant 1	Assosciate Professor for Suppl Chain Management

The results, shown in Fig. 2, show a high level of agreement with the indicators mentioned in the first round. The indicators 'power supply', 'influence environment' and 'costs for transponders' in particular show a very high level of agreement in both rounds. However, all of them achieve an average agreement above the level of "I agree". There were minor adjustments in the second round, but this didn't change the basic message of the answers. The results of the study show a high level of agreement with the indicators and their attributes and it can be assumed that the selected indicators can be used to describe asset tracking applications.

Participants were also asked about the potential that they assign to a particular characteristic of an indicator. For example, one of the questions was: How do you estimate the potential of the 'number of assets' indicator with the attribute 'up to 1,000 assets? In this scheme, all indicators and attributes were queried in order to obtain an assessment of the influence of these indicator attributes on the potential. A correlation between the attributes of an indicator and the potential of an application was derived from the collected responses. By rating the attributes of the indicators from 1-5, the influence of the respective attributes can also be quantified and then summarized to an overall potential.

Fig. 3 shows the results from the delphy study for the indicator 'amount of assets'. The assigned potential increases with the amount of assets are used. It seems to increase in a linear way, expect between 6 and 100 assets there is nearly the same value. This result is due to the fact, that the impact on maintenance and operation of the tracking-system is estimated almost equally by the experts. From higher asset numbers (more than 1,000), lower costs per asset for maintenance and operation are assumed and the potential increases continuously.

Lower asset numbers show normally less potential. This result can be argued with the fact that fewer synergy effects will occur here, as individual assets usually have little influence on the overall process. However, a low number of assets is a good starting point for companies to get into the field of asset tracking, as the investment costs remain manageable.

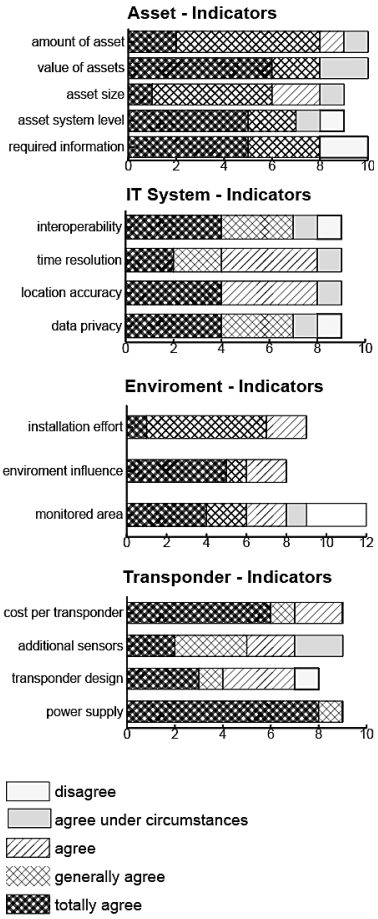

Fig. 2. Results of the delphy study for asset tracking indicators.

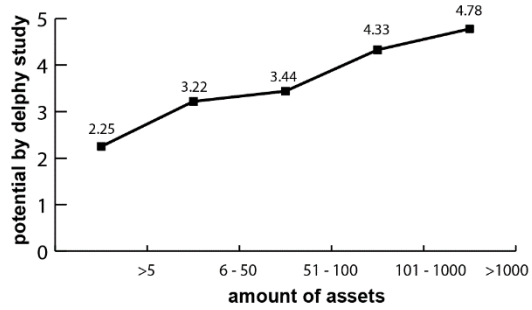

Fig. 3. Relation between potential and amount of assets.

These analyses were carried out for each indicator, but are not listed here due to the lack of space. Therefore, all relations of the indicators can be found on github.com[1].

[1] https://github.com/chrisLeeFhstp/asset-trackin-potential-analysis

The next phase in determining the potential of an asset tracking use case is to assign the relevant attributes to all indicators and then sum up the corresponding potential. The following steps are necessary to get a result:

1) Assign an attribute and the corresponding potential value to all indicators of the use case to be determined. For example, the number of assets in the specific use case is 256. As this value is between 101 and 1,000, the potential value is assumed to be 4;
2) The second step is to sum up the determined values at indicator level. Due to the fact that not all indicators have five possible attributes, it is first necessary to normalize all values. These values are then summed according to the indicator levels from Fig. 1. For example, for the context level potential, the values of the indicators area size, installation effort and environmental influence must be added together in order to capture this partial potential;
3) The total potential can then be calculated using the Formula 1, where P_{total} stands for the total potential of an asset tracking application and ($P_{asset}, P_{env}, P_{trans}$ and P_{sys}) stands for the potential of the different indicator levels;
4) The values obtained for the partial potentials can be transferred to a spider-diagram, as shown in Fig. 4, for visualization. This makes it easier to compare different use cases, but also to better understand the distribution of the total potential across the different indicator levels.

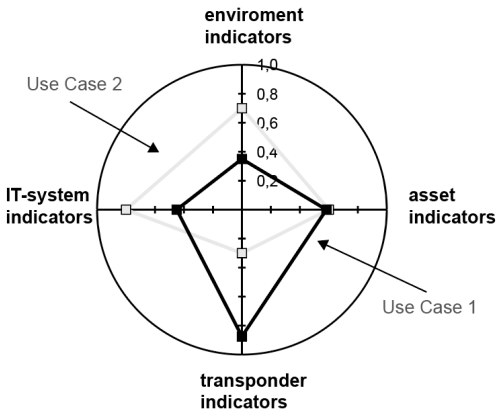

Fig. 4. Visualisation of the proposed potential analysis for asset tracking use cases.

5. Discussion

The proposed indicator-based potential analysis model for asset tracking applications provides a novel approach to evaluating and selecting suitable technologies based on specific use cases. This

methodology leverages a set of validated indicators, encompassing various factors such as asset characteristics, environmental conditions, transponder specifications, and IT system requirements. By systematically analyzing these indicators, the model allows for a structured assessment of different asset tracking solutions, thereby enabling organizations to make informed decisions.

Calculation of the total potential of an asset tracking use case:

$$P_{total} = \frac{P_{asset} + P_{env} + P_{trans} + P_{sys}}{4} \quad (1)$$

One of the primary strengths of this model is its simplicity and accessibility. Unlike more complex decision-making frameworks that require deep technical expertise, this model is designed to be intuitive and user-friendly, even for individuals without specialized knowledge in track and trace systems. The model can also be used to find out how to increase the potential of track & trace applications.

For this, the partial potentials and the numerical values assigned by experts can help to increase the overall potential and thereby strengthen the entire use case in its innovation.

However, the model also has its limitations. Given its design simplicity, it may not capture all the nuances and complexities of more advanced asset tracking scenarios, especially in highly specialized environments or in the comparison with use cases, which are quite similar.

Additionally, while the model provides a valuable starting point, it may not fully account for evolving technological advancements or unexpected changes in operational requirements. Therefore, while the model can effectively guide initial decision-making, companies might need to supplement it with additional, more detailed analyses or expert consultations for final decision-making.

6. Conclusion

The indicator-based potential analysis model presented in this study offers a pragmatic and structured approach for evaluating asset tracking applications across various use cases. By using a validated set of indicators, the model provides a clear framework for companies to assess and compare different asset tracking solutions, facilitating more informed decision-making. While the model's simplicity makes it accessible and easy to use, especially for non-experts, it also highlights the importance of balancing simplicity with comprehensiveness to ensure robust evaluations.

The study's findings underscore the utility of this model in supporting companies to optimize their asset tracking strategies, potentially leading to enhanced operational transparency and efficiency. Moreover, the high level of agreement among experts regarding the model's indicators reinforces its validity and applicability in real-world scenarios. As the field of asset tracking continues to evolve, future iterations of the model could incorporate more dynamic and responsive indicators, further improving its effectiveness as a decision-support tool.

Overall, the proposed methodology provides valuable insights into the potential of different asset tracking applications, enabling organizations to maximize their investments in tracking technologies and ultimately enhance their competitive advantage in the marketplace.

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