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Procedia CIRP 136 (2025) 117–122

www.elsevier.com/locate/procedia

35th CIRP Design 2025

Eco-Efficiency – Environmental Indicators for Service Systems

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Abstract

Eco-efficiency provides a benchmark for assessing sustainability and suitable measures to improve it. To date, no indicators for measuring the eco-efficiency of service or product-service systems were established. The aim of this paper is to identify and select suitable environmental indicators for assessing the eco-efficiency of such systems using a developed framework. Finally, the appropriate identification of suitable indicators for service and product-service systems enables the optimisation of sustainability and thus, creates a basis for the application and review of eco-efficiency assessment in science and practice. In this way, eco-efficiency assessments can be carried out in relation to the specific characteristics of service and product-service systems.

Keywords: Servitization eco-system; Sustainability for PSS solutions; Industrial Product-Service Systems (IPSS)

1. Introduction

Different theories and approaches were described to assess the eco-efficiency of product systems in particular and in general. However, in case of service systems or Product-Service Systems (PSS), there is no common approach for the selection of indicators and the assessment of eco-efficiency. The literature covers a wide variety of opinions on the correct use and application of eco-efficiency frameworks [1-3]. However, Rashidi et al. states that most Eco-efficiency Indicators (EI) focus on companies or product-oriented systems [4-5] but no comprehensive model for the calculation of eco-efficiency was yet established [6]. For Service- or PSS no framework for the systematic identification and selection of EI is common and tested.

The aim of this article is to provide a framework for the identification of EI for service- or PSS. For this reason, this paper will focus on the systematisation and operationalisation of service- and PSS to elaborate a framework and flowchart for the selection of environmental EI. This approach enables the selection of EI based on an input and output analysis. According to the World Business Council for Sustainable Development from 1992, eco-efficiency takes into account both, ecological improvements and economic benefits. The main purpose is to add value whilst reducing the environmental impact [7]. According to Hart et al., there is a clear correlation between environmental performance and financial savings in terms of EI [8]. Charnes et al. present the concept of relative efficiency as a profound basis for decision-making as an alternative to the empirical economic approach in the case of missing or insufficient data [9]. Eco-efficiency is a broadly accepted concept in the field of sustainability performance assessment of industries or technical systems [10-11]. To calculate eco-efficiency, it is important to identify and select the relevant indicators in the beginning. A major advantage is that companies already have experience with this type of measurement and the data for such indicators is widely available [12]. The framework presented in this paper is based on EN ISO 14045 and EN ISO 14040. The EN ISO 14045 is the theoretical basis for the concept of eco-efficiency assessment [13]. The EN ISO 14040 forms the fundament for the approach to developing the framework and hence, the theoretical basis for adapting the phases and the procedure to the demands of eco-efficiency [14]. As a result, various adjustments need to be undertaken to develop a framework for the selection of environmental EI services or PSS.

10.1016/j.procir.2025.08.022

2. Methodology

The objective of this paper leads to the following research question: How can a framework to identify and select suitable EI for service- or PSS be developed? To answer the research question, the methodology was applied according to Figure 1. The first step was to conduct a literature review. The literature review and analysis included especially internationally recognised and valid standards. The literature review was conducted as a Systematic Literature Review (SLR), which contains the formulation of the question, locating studies, selecting and evaluating these, analysing, synthesising, and reporting the use of results. Based on the literature and internationally recognised standards, service systems can be systematised in step two. Here, the model of the four dimensions of service systems according to Abdel Razek et al. was chosen. Furthermore, environmental indicators according to [15] were identified and formed into groups. Next, operationalisation was carried out on the basis of systematisation. Especially, the approach of the EN 14040 was adopted and extended for the identification of the indicator groups. It was determined how the characteristics can be quantified or qualified and how they can be made measurable. The theory synthesis is carried out to achieve conceptual integration. In this step, the different concepts and methods were synthesised. On this basis, the modelling was achieved leading to the framework for the EI selection. Thus, an input and output analysis were applied to identify EI and, depending on requirements, to evaluate them qualitatively or quantitatively or to enable a selection of suitable indicator groups. Finally, a concept and framework suitable for the selection of indicators was derived and evaluated, and the research question was answered accordingly.

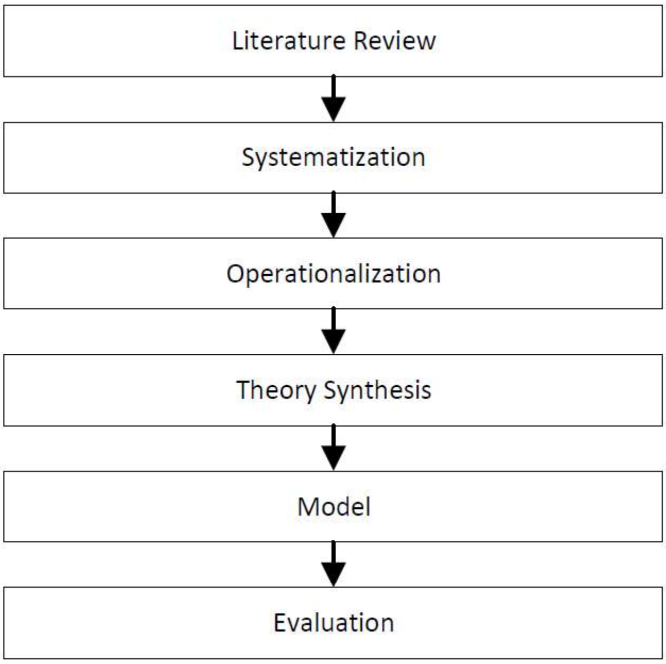

Fig. 1: Methodology Adopted in this Study

3. Approach for the development of the framework

To be applied in practice, the framework has to be based on standardized procedures that are both, manageable and practicable for companies. In particular, the procedure has to be designed to be incorporated into existing processes. For this reason, the process was based on international standards and expanded as required. As this is a widely used and successfully applied methodology, the framework developed is compatible with established approaches. In this manner, a process and criteria framework was developed to determine suitable EI for service or product-service systems. In addition, the approach was designed in such a way that either a quantitative or a qualitative approach can be applied. This means that data, where available, can be included in the analysis from the beginning. However, if data is not available, the resources required can be estimated as part of the input-output analysis. The phases of a life cycle assessment according to the EN ISO 14040 was adapted as demonstrated in Figure 2. The phases were adopted for the purposes of the EI analysis. Since the focus is on determining the inputs and outputs of the system under consideration, determining the life cycle assessment is a similar approach to eco-efficiency. For this reason, the approach is well suited for the transfer to the concept of eco-efficiency. The three phases goal and scope definition, inventory analysis and impact assessment were retained in the basic structure. Goal and scope definition is transferred identically. The inventory analysis was renamed to “Eco-Efficiency Service or Product-Service Inventory Analysis” as well as the impact assessment to “Eco-Efficiency Service or Product-Service Indicator Selection”. The first step is to define the scope of the analysis and the objective. This forms the basis for the further course of identifying the suitable EI for service- or PSS. The level of detail and time frame of the investigation

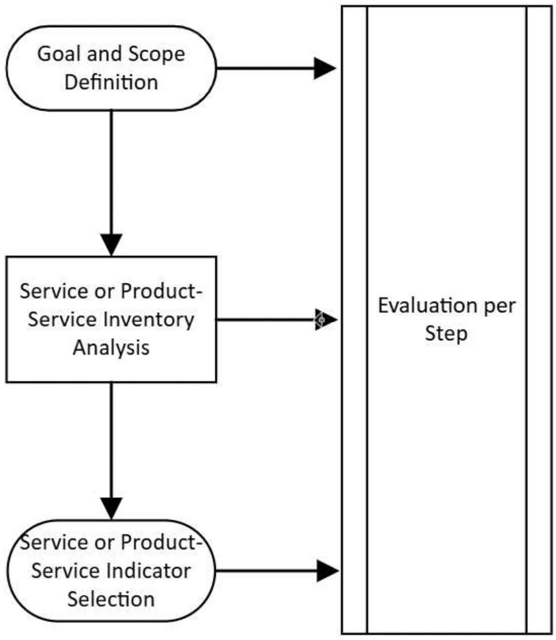

Fig. 2: Phases of the Eco-Efficiency Inventory and Indicator Selection Analysis

can vary greatly depending on the objective and scope of the analysis (EN ISO 14040). The eco-efficiency inventory analysis takes inputs and outputs over all the process into account. By understanding the inputs and outputs within the service system process, correlations with environmental indicators can be checked. This approach assumes that the inputs and outputs of the service system sufficiently represent and describe the object of the investigation. Therefore, it must be expected that influences on the environmental dimensions can be investigated by inputs and outputs. However, especially in the case of chemical or biological processes, substances can be created in different steps, that are not identified in a pure input and output analysis. In such a case, the inputs and outputs of individual process steps should be taken into account. The scope of this approach is not to develop and optimize service or PSS, but to identify indicators for an eco-efficiency assessment.

4. Phases of the eco-efficiency indicator analysis

To provide an overview of applicable EI, Glauninger (2024) analysed EI of different industries related or suitable for the assessment of eco-efficiency of service- or PSS. 48 different environmental EI, which were mentioned 229 times in 51 publications could be identified and formed to six indicator groups [15]. Under consideration of the diversity due to different circumstances of service provision, the EI are not applicable for services of any kind. Therefore, these indicators or better their indicator groups should be analysed in reference to a service system to proof their suitability for the specific systems. In regard to various opinions for the correct use and application of eco-efficiency frameworks [2-3] and the application of different types of EI in different sectors, a consistent approach is needed. The phases of the framework will be described in the following sections.

4.1. Goal and Scope Definition for Service or Product-Service Systems

In total, 4 phases, illustrated in Figure 2, were adjusted according to ISO [14]. The first phase contains steps, which are shown in Table 1 to set the scope of investigation.
The goal and scope definition contains seven steps. In comparison to EN ISO, the impact categories are not selected in the first step. This is because the aim is to define the impact categories, i.e., to identify suitable dimensions or specific indicators of the environment. Furthermore, for the scope of the analysis, the phases were streamlined, and those points that occur in a life cycle assessment but are not required for the purpose of this study were omitted. The aim of the steps is to define the necessary limits and scopes to be able to carry out the analysis systematically.

Table 1. Steps of the Goal and Scope Definition [14]

Step	Goal and Scope Definition
1	the service or product-service system to be analyzed;
2	the functions of service or product-service system;
3	the functional unit;
4	the system boundaries;
5	Allocation procedure
6	the assumptions;
7	the restrictions;

4.2. Eco-Efficiency Inventory Analysis for Service or Product-Service Systems

According to Charnes et al., data for the exact determination of eco-efficiency should be applied if they exist. However, if exact data is not available, estimations must be used [9].
The aim of the inventory analysis is to identify the relevant inputs and outputs of a service or product-service system. If a further assessment of eco-efficiency is planned, quantification can already be carried out in this step. However, quantification is not necessary for the step of identifying suitable indicators. If a quantitative approach is possible, data has to be collected as seen in the following Figure 3. Relevant EI are determined on the basis of inputs and outputs. This step can be organised iteratively so that a more detailed analysis can be carried out if necessary or the system has changed or been modified. Various inputs and outputs can be considered for data collection or the estimation of possible inputs and outputs. Depending on the specific service- or PSS, the process can be very complex [14]. The standard (EN ISO 14040) proposes indicator groups to categorise the life cycle assessment. This has the advantage that not all indicators being relevant for an indicator group have to be listed. Based on Glauninger et al. [15] and the EN ISO 14040, indicator groups of EI according to Table 2 were noted, which serve to summarise the various EI. The advantage of this approach is, that the groups help to structure and to gain an overview of possible relevant inputs and outputs in their identification of suitable indicators for a quantitative or qualitative analysis [16]. The specific indicators of the indicator groups are not shown due to the scope, but are published by Glauninger et al. [15].

Table 2. Inventory Analysis – Indicator groups [14-16]

Group No.	Inventory Analysis for Service or Product-Service Systems – Groups of In- and Outputs
I	Energy
II	Water
III	Material
IV	Greenhouse Gases (GG)
V	Environmental Damaging Substances (EDS)
VI	Others

As a next step, the relevant inputs and outputs are determined. For this purpose, relevant inputs and outputs are assigned to each indicator group. Table 2 shows a basic structure for this purpose; the more detailed the analysis of inputs and outputs, the more valid the identified groups will be. If several indicators come into question for an indicator group, these should be listed accordingly within the group. The aim is to exclude those indicator groups that do not play a role in the specific service or PSS and to select the indicator groups that are important for the specific service or PSS. If quantitative data is already available, it is recommended to enter it directly into the table as the process continues. For example, for indicator group II, the amount of water consumed can be calculated, or for indicator group I, the amount and type (renewable vs. non-renewable) of energy consumed in kilowatt can be determined. In principle, an estimation can be made on a qualitative basis. However, such a consideration will never approach the accuracy of quantitative data. If no data is available, e.g., because a newly created service- or PSS needs to be considered, it is advisable to enter either estimated quantitative data (for later comparison) or a qualitative estimation using, for example, numerical values from 1 to 5 as suggested by Glauninger [16]. For simplicity, a binary format has been chosen for the 3 table. “N“ stands for no and “Y“ for yes.

Table 3. Basis Input-Output-Analysis Structure

Input-Output Analysis	Energy	Water	Material	GG	EDS	Others
Input	Y	Y	Y	N	Y	N
Output	N	N	N	Y	Y	Y

In case of a quantitative assessment, it is recommended to follow the structure of the eco-efficiency assessment for service- or PSS in agreement with Glauninger et al. [16]. For this purpose, the data can be transferred directly to the potential analysis or the detailed analysis. This includes a breakdown of the service or PSS according to the service dimensions [17]. The service component is classified into four dimensions, Actor(s), Artifact(s), Setting, and Process. The structure is shown in Table 4. For each dimension, the input and output are recorded separately. Here, a major advantage is that an eco-efficiency assessment allows an evaluation of the improvement for each dimension. This enables a more detailed recording and a more in-depth analysis of the impact of an improvement of the eco-efficiency. Finally, the impact of an improvement can be better captured; for example, if an improvement is achieved in a single dimension, this can make a clear difference to an impact on all dimensions for analysis. Table 4 shows the input analysis, whereby the indicator groups are presented in the columns and the service dimensions in the lines. The indicator groups that are relevant for the specific service or PSS must be defined. For a better understanding, the indicator groups for a service call to repair a technical component were illustrated as an example. The service technician, here the actor, is irrelevant for energy or energy consumption in this case. The Artefacts, however, the vehicle, the laptop and further tools require energy, water such as windshield washer fluid for the vehicle, materials for the maintenance and care of the equipment, environment damaging substances such as fuel for the vehicle and outputs greenhouse gases. Further, environment damaging substances such as hazardous waste and others such as regular waste can be an output. The indicator group no I. is therefore answered in the affirmative for the Artefacts. Other forms of energy consumption can occur in the service provider's office space or, for example, in warehouses. Energy used in processes that do not directly affect the environment, the actor or the artefact must also be considered. These include those processes that are relevant to the delivery of the service. In this case, this could be the energy consumed by the server infrastructure that enables a remote connection to the machine's sensors.

The variation of possible indicator groups is represented as a propositional logic formula for the input analysis as follows. To better describe the different options, propositional logic expression was used. The system described here consists of six main indicators I_1, I_2, I_3, I_4, I_5, I_6 each of these contains four further indicators representing the service dimensions. The link between the indicators is embodied by the OR operation (V). The overall result is positive if at least one specific indicator of an indicator group is true as shown in the propositional logic expression:

$$(I_{1_1} \vee I_{1_2} \vee I_{1_3} \vee I_{1_4}) \vee (I_{2_1} \vee I_{2_2} \vee I_{2_3} \vee I_{2_4}) \vee (I_{3_1} \vee I_{3_2} \vee I_{3_3} \vee I_{3_4}) \vee (I_{4_1} \vee I_{4_2} \vee I_{4_3} \vee I_{4_4}) \vee (I_{5_1} \vee I_{5_2} \vee I_{5_3} \vee I_{5_4}) \vee (I_{6_1} \vee I_{6_2} \vee I_{6_3} \vee I_{6_4}).$$

Table 4. Input-Analysis Detailed Structure

Input-Analysis	Energy	Water	Material	GG	EDS	Others
Actor(s)	-	-	-	-	-	-
Artefact(s)	4	1	3	-	3	-
Setting	2	-	-	-	-	-
Process	2	-	-	-	-	-

In Table 5, the output analysis is presented. This leads to a similar propositional logic formula for the output analysis: $O_1 \vee O_2 \vee O_3 \vee O_4 \vee O_5 \vee O_6$. The distinction between input and output was chosen to be able to identify all relevant substances and to record the changes in the further course better. These also each contain four sub-items representing the service dimensions.

$$(O_{1_1} \vee O_{1_2} \vee O_{1_3} \vee O_{1_4}) \vee (O_{2_1} \vee O_{2_2} \vee O_{2_3} \vee O_{2_4}) \vee (O_{3_1} \vee O_{3_2} \vee O_{3_3} \vee O_{3_4}) \vee (O_{4_1} \vee O_{4_2} \vee O_{4_3} \vee O_{4_4}) \vee (O_{5_1} \vee O_{5_2} \vee O_{5_3} \vee O_{5_4}) \vee (O_{6_1} \vee O_{6_2} \vee O_{6_3} \vee O_{6_4}).$$

In the case of the output analysis, a different picture emerges for the selected example as shown in Table 5. No outputs are determined for indicator groups I-III, but there are for groups IV-VI. Greenhouse gases are generated by vehicle transport, by offices using heating oil to provide heat or by operating the server infrastructure proportionally through coal-fired power plants.

Table 5. Output-Analysis Detailed Structure

Output-Analysis	Energy	Water	Material	GG	EDS	Others
Actor(s)	-	-	-	1	-	-
Artefact(s)	-	-	-	4	4	3
Setting	-	-	-	3	-	-
Process	-	-	-	3	-	-

Environment damaging substances (group V) play a role here, as, for example, tyre wear, or hazardous waste such as batteries that need to be discharged can occur. With regard to group VI "Others", such as waste that does not have a direct negative impact on the environment but causes problems, such as the recycling of normal waste, packaging waste from spare parts was identified.

4.3. Eco-Efficiency Indicator Selection Analysis for Service or Product-Service Systems

In contrast to the EN ISO 14040, no quantitative acquisition is needed. The aim is to identify suitable indicators for an eco-efficiency assessment. If a quantitative approach is planned, it is recommended to collect and insert the specific data into the table template by using the appropriate units. In such a case, the specific indicators according to each indicator group, if existing, can be included into the input or output analysis.

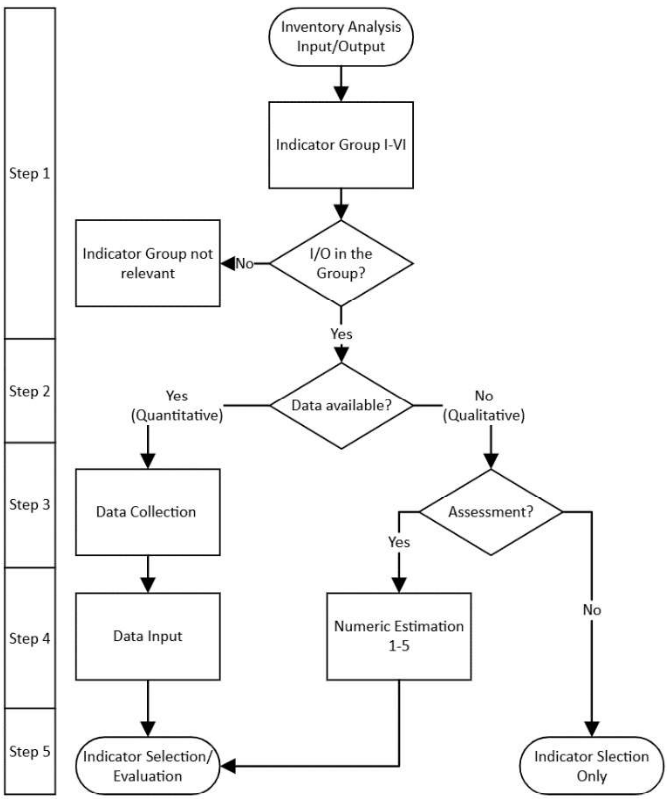

Fig. 3: Qualitative and Quantitative Approach for Indicator Selection

Figure 3 shows the approach for the quantitative or qualitative analysis. The first step has to be applied separately for each indicator group. Its scope is to identify outputs and inputs being related to an indicator group. This is used to determine which indicator groups have to be selected. If an indicator group is relevant to the input or output analysis, for example, the output of CO_2, the corresponding indicator group is selected. If the relevant indicator group is selected, the type of input and output analysis must be taken into consideration. Therefore, in step 2, the decision to analyse qualitatively or quantitatively is made. In the case of quantitative analysis, there is an intermediate step, data collection and data entry. The data, for example the amount of CO_2 released, can be entered here. The final step is the evaluation of the results. If no data is available, a qualitative approach should be considered. This takes place in step 3, in case of the qualitative assessment, two approaches are possible. Here, either the presence of inputs or outputs can be qualitative assessed using the binary decision from step 1 or a numerical estimation of 1-5, for example, as seen in step 4. In the end, the qualitative approach leads either to the selection of eco-efficiency indicator group and evaluating the results or to the indicator selection only. In case of indicator selection only, the output of the selection contains no assessment and therefore, no evaluation. In the quantitative approach, step 5 leads to the selection of indicators and evaluation as well. If this occurs, step 3 is defined as data collection and step 4 as the data input. The process should be repeated each time, the service or the PSS is modified. For example, if the route to the customer of a service is replaced by a remote solution. This can have a significant impact on the input and output analysis and thus, on the selection of the indicator groups. The inputs listed above yields the following contents listed in Table 6.

Table 6. Eco-Efficiency Indicator Group Selection Result

Input-Output Analysis	Energy	Water	Material	GG	EDS	Others
Input	8	1	3	-	3	-
Output	-	-	-	11	4	3

Finally, the indicator groups I-VI can be selected as relevant for the service- or PSS in this case. Four of the six indicator groups are relevant for the input analysis. Three relevant indicator groups were identified for the output analysis. For a more precise and in-depth analysis, the specific indicators according to each indicator group can be considered for analysis. Furthermore, if output and input are addressed separately, the respective indicator groups that are not relevant can be excluded from the analysis from the beginning. The identification of the indicator group is very useful for the first step. The first eco-efficiency assessments can now be carried out and the selected indicator groups can be used for this purpose.

5. Discussion

The combination of services and products to PSS could positively influence the eco-efficiency improvement. Froböse et al. outline that the combination of service and product to form PSS can increase eco-efficiency by a factor up to 4-10 compared to the pure product use. Approaches are required that are suitable for service systems and can also be adapted to PSS [18,19]. Hybrid systems that are able to be transferred either from services systems to PSS, or vice versa, are particularly suitable for this purpose. For this purpose, international standards were used to synthesise the theory. The approach of defining and selecting the EI individually for each service or PSS has the great advantage that the range of potential applications is significantly increased. In particular, since enormous numbers of EI are available and possible, an exhaustive list cannot be given. For example, new processes and new technologies can lead to new substances or emissions that were not yet included into any previous analysis. The complexity and diversity of service or PSS is therefore incompatible with a fixed number of EI. Nevertheless, certain indicators became established in some areas, particularly for product systems in some industries. The defined indicator groups serve as a summary of various indicators and thus, form a basic structure. In addition, it is not only relevant whether there are inputs or outputs. Regarding energy, for example, different forms of energy production can be considered. Depending on if they are renewable or non-renewable, they have a different impact on sustainability. This also applies to other indicator groups, i.e., water. Therefore, this should be analysed in more detail, especially in the step of evaluation. The more detailed the input-and output analysis is applied, the more precise the selection of the environmental EI can be.

6. Contributions and future research

Through the broad application of the framework presented and further research work that integrates the concept, further empirical evaluations can be carried out to identify suitable EI for service- and PSS in different sectors. By analysing different industries and sectors, it might be possible to determine appropriate EI for different industries or functional units of service- or PSS. This could simplify an analysis by allowing individual steps to be shortened or omitted. This framework can be included into existing eco-efficiency assessment procedures. In this way, already established concepts and procedures can be refined. Furthermore, a framework to identify and select economic EI should be carried out in advance. The basis for an eco-efficiency assessment is only provided when both sides of the eco-efficiency equation were captured and the corresponding indicators for the service- or PSS can be recorded easily. Finally, the framework provides a basis for the development of a procedure to assess the potential for improving eco-efficiency, in combination with existing concepts [16]. In a later stage of the development, a prototype to create a computer-based evaluation procedure would be beneficial and thus, enable a practical application. Based on the prototype, further insights can be generated and understanding increased.

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