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Comparative evaluation of product and service solutions in the context of Product-Service Systems and Technical Inheritance

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Abstract. With the increase of Product-service systems being implemented, it is necessary to evaluate whether a function should be provided as part of the physical product or as a service. Therefore, it is required to evaluate which of the possible solutions is objectively better. For these 3 major factors have to be evaluated and be put into a comparative relation. The three major factors considered are requirement fulfillment, cost and ecological impact. The calculation for comparative scores that describe the relative quality of each solution for these three values is explained. The separate scores are aggregated into to one score on which the solutions are compared to find the best solution. The method is then used in a case study. Which focuses on an electronic object carrier sorting system, for which a new product generation is planned. This is achieved by following the process of technical inheritance in combination with the method proposed here to evaluate the different possible solutions.

Keywords: Product-Service System, Product Development, Technical Inheritance.

1 Introduction

The number of publications with Product-service systems (PSS) as a subject matter has been increasing rapidly over the last years [1]. Where it is usually defined as a combination of products and service to fulfil customer needs [2]. Although not many companies market their products as PSS there are indicators that suggest that the adoption of PSS has become much more widespread. In order to stay competitive and to insure more regular cash flow many companies a transforming their business models to either contain services or offer their products as services instead [3].

PSS contain at least one product and one service component and their combination is used to fulfil customer needs. The services in a PSS can take many form and can be a supplementary offering or can be a core part of the product function. This means that not all customer requirements have to be realized in a product. But instead it is possible to realize them through a service that can fulfil the same requirement. For example,

product reliability can be fulfilled through ensuring that the technical components of a product meet the reliability requirements. Alternatively, the overall reliability of the product could be achieved by including a maintenance service that ensures the specified reliability requirements are met. With this a product is transformed into a PSS, which leads to new decisions during the product development process which have to be made. During the design of conventional products decisions have to be made on which design alternative is best to fulfil the product requirements. This is a field that has been thoroughly explored and resulted in many methods such as *Decision matrix analysis*, *Technical-economic assessment* and *Cost-utility analysis* [4; 5; 6]. But these methods do not consider the comparison of technical components against service components as possible solutions to fulfil the product requirements. Therefore, it is necessary to find a structured approach that allows for the evaluation of technical against service solutions in an objective manner. Which leads to the question this paper tries to answer: “How does a methodical approach for evaluating technical against service solutions in PSS on their suitability for requirement fulfilment have to look?”

2 Research Background

2.1. Product Service Systems

Product-Service Systems have been defined as the combination of products and services that jointly fulfil a customer need [2; 7; 8]. To which degree the customer need is fulfilled by product or service components is flexible. But if either one is used alone it is no longer a PSS. When discussing PSS the product component is considered to be tangible content. This tangible content is represented in the form of physical artifacts. While the service component of the PSS is considered to be intangible. Which means that the services are produced and consumed simultaneously [2].

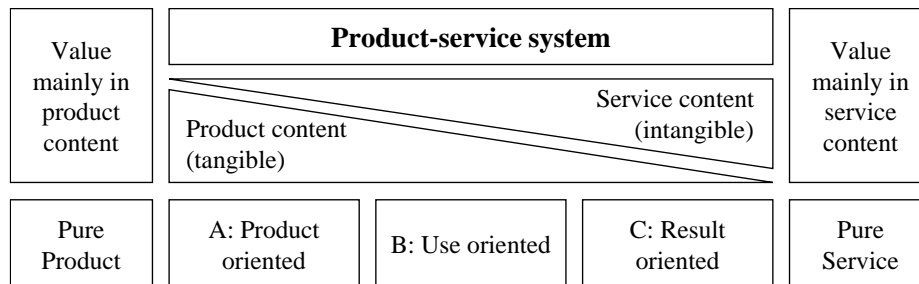


Fig. 1. PSS Classification [2]

It is possible to classify PSS into three major groups based on their level of service integration [2; 9]. These three distinct groups are shown in Fig 1 and referred to as product oriented, use oriented and result oriented. In the product-oriented category there is still a transfer of ownership between the PSS operator and the customer and the services are only supplementary. Use oriented PSS are where the traditional sale of

products is no longer an objective and the product ownership remains with the PSS operator. The product is then made available to customers for limited times. Third is the category of result-oriented PSS in which only a result is agreed upon and not a predetermined product that will be used to achieved said result [2]. While other researcher occasionally classify PSS in a different manner they usually aim to increase the precision of the different classes. For example, Tan has described PSS as a combination of seven strategic characteristics that can take different form depending on the PSS [10]. Alternatively, Mont has [11]. Ultimately it is possible to reassign these sub-categories back to the categories proposed by Tukker and since the degree of granularity is sufficient for this paper this is the understanding of the term PSS which this paper refers too.

2.2 The Concept of Technical Inheritance

Technical Inheritance is defined as a transfer of assembled and verified information from development, production and application to the next product generation [12; 13]. Based on collected and verified information components are adapted and optimized for the next generation. Deduced from evolutionary mechanisms from nature mechanisms for the evolution of technical products are adapted and determined.

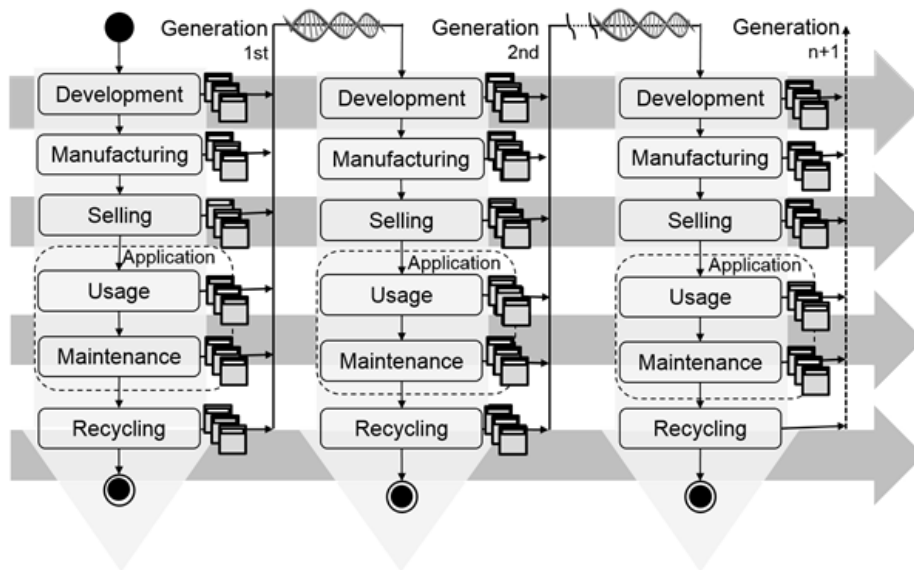


Fig. 2. Transfer of life cycle data [12]

The proceeding of an intergenerational development includes four steps. First, the needed life cycle information have to be identified. Second, the monitoring strategy has to be implemented. Third, a Data Mining method has to be realized and finally the information has to be transferred back to the development for a new product generation

[14]. Within the product development the life cycle information is analysed and requirements for the new product generation are defined [15]. If a requirement is implemented as a new technical solution or as a service a decision matrix is used.

2.3 Methods for Evaluation

The assessment of complex decision problems requires a systematic use of principles, such as weighting, aggregating or scoring, based on criteria, functions and algorithms [16]. In applying these principles, errors within the evaluation must be minimized by checking objectivity, plausibility and sensitivity to evaluate criteria with equal evaluation standards and allow constraints for robust decision processes [17, 6]. Depending on the quality of these decisions, the "pair-wise comparison", the "technical-economic evaluation" and the "utility analysis" offer different methods to capture the complexity and the implementation time.

Decision matrix analysis/ pairwise comparison. The "pairwise comparison" or "decision matrix analysis" allows a decision to be made on a comparison of different alternatives with low input [4, 18]. All considered alternatives X_i are listed in a decision matrix as lines and all available evaluation criteria C_j as columns. The evaluation of these criteria can be analysed column by column according to the "best" alternative [4], allowing a ranking of all alternatives based on the preferences to be created (cf. Figure 3) [18, 6].

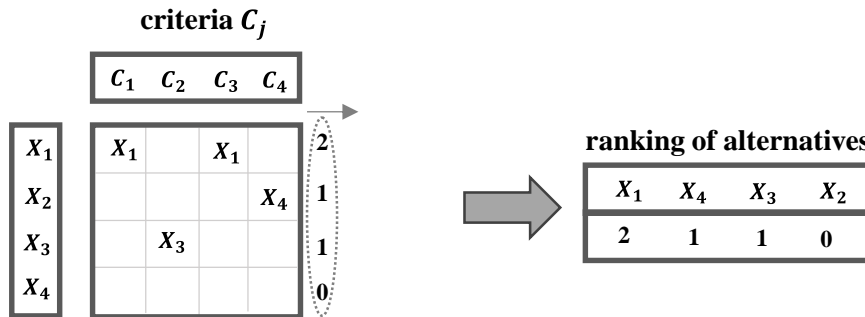


Fig. 3. Decision matrix according to Alabool et al. [4]

The method is limited in its objectivity, as the outputs correlate directly with the subjective perceptions of the user. In addition, the use of a decision matrix for complex problems is very time-consuming and limited in terms of illustrating multi-criteria interactions [4]. An improvement of this method is the "analytic hierarchy process" (AHP), as a weighting is integrated to select the preferred alternative which has a direct influence on the resulting hierarchy of alternatives [16, 19].

Technical-economic assessment. The "technical-economic evaluation" according to the VDI 2225 for "technical-economic design of complete technical products" is used

for decision-making by a systematic classification of available alternatives [5, 6]. In contrast to the AHP, unordered criteria are listed at the beginning of the assessment and indicators are allocated to represent the fulfilment of these criteria for the alternatives concerned. In addition, the various criteria are weighted against one another to be able to prioritise these [18, 6].

The technical valence x describes the weighted average value for all criteria of the alternatives considered [5]. Analogously, the economic valence y is composed by the ratio of the ideal and the actual manufacturing costs for the respective alternatives [5]. In addition to the economic and technical valence, the total valence is defined as the "strength" s and shown graphically (cf. Figure 4) [18, 5, 6].

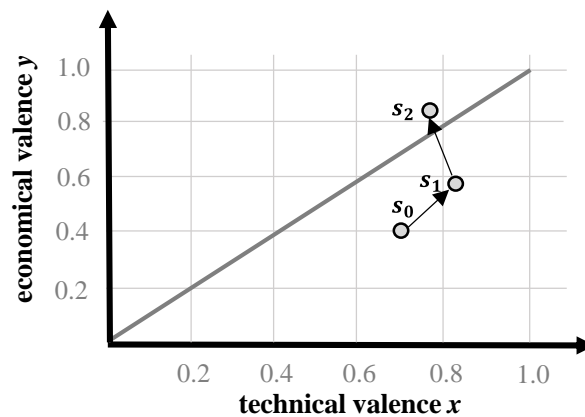


Fig. 4. Strength diagram according to VDI2225

This method, which requires a lot of time to implement, is a systematic and transparent approach for evaluating complex decision problems and, in comparison to pairwise comparisons, enables a higher quality of the results [18, 6].

Cost-utility analysis. Dealing with complex decision tasks requires a clear method for evaluating a large number of different evaluation criteria and determining the relative value of a considered alternative [6]. These assessment criteria are hierarchically ordered in form of a system of objectives according to their complexity as well as the intended objective areas for rating the relevance of the defined sub-objectives of lower order in the total context. This resulting decision tree comprises nodes as well as order-specific values [20].

For weighting the different evaluation criteria, values between 0 and 1 are used, which always add up to 1 in their order [20]. Within this weighting, a distinction can be made between ordering and knot weightings. As the order weighting is the product of all position-specific knot weights in ascending order, the calculation of these knot weights has priority [6].

Following this calculation, characteristics are determined for the various alternatives and links to the considered assessment criteria are created, which depend on the fulfilment of these criteria and is deposited with values of an ascending scale [6]. As the resulting total utility value and the result of the assessment, the values are multiplied with the weightings and summed up in accordance of the relevant assessment criteria [6].

Ecological Impact. To be able to make a conclusion regarding the ecological impact related to the comparison of a technical material product solution and an immaterial service component, the definition is not standardised [21]. Regardless of the chosen categories and indicators for impact assessment, a consistent functional unit must be defined first, on the basis of which the comparison is made [22]. One possibility is the assessment of resource productivity, which can be applied to both products and services by means of various raw material indicators, such as the cumulative energy analysis (CEA) [23]. According to the ecoinvent database, the CEA considers the following factors [24]:

- wind, renewable energy resources, kinetic;
- water, renewable energy resources, potential;
- solar, renewable energy resources, conventional;
- primary forest, non-renewable energy resources;
- nuclear, non-renewable energy resources;
- geothermal, renewable energy resources;
- fossil, non-renewable energy resources;
- biomass, renewable energy resources.

The CEA is an easy-to-use screening indicator that can be seen as an introductory method to conventional life cycle assessment that calculates MJ equivalents as its result [24].

3 Defining Requirements

As shown in section 2 when comparing different solutions in the product design process it is necessary to consider the costs of the design alternatives, since a product that is financially not viable cannot survive long term in a competitive market. Furthermore, it is necessary to evaluate how well the different alternatives fulfil the customer requirements, because if a product does not sufficiently fulfil customer requirements it will not be bought. In addition to these two factors that are both imperative for the overall success of a product the ecological impact of products has come more into the focus of product developers in recent years. Therefore, the developed method must contain an evaluation of the fulfilment of customer requirements, costs of the product and also allow for an ecological evaluation. Additionally, an option to prioritize these three factors when evaluating the alternatives would be advantageous to ensure that the method can be customized if business strategies or market forces lead to a higher importance of a given factor. Established methods such as those presented in section 2 are

focused on evaluation of these factors independent of each other and given no explicit recommendation which solution should be chosen based on the results for the individual factors. Furthermore, the evaluation of requirement fulfilment focuses either on a comparative evaluation solely based on which one is better or on an evaluation based on requirement fulfilment with certain degrees of fulfilment. The developed method should therefore be able to show which solution is better in fulfilling a requirement and to which degree. Additionally, methods for the calculation of ecological impact are not designed to be utilized for the use with services. Which highlights the necessity that a method is developed that is also applicable to services and products to allow cross comparability.

4 Method

As described in section 3 the method for comparing service and product solution against one another needs to take into account three different areas fulfilment of the requirements, cost of the solution and its ecological impact. But before these are compare it is important to first determine if a service solution is even possible. This means that it must be feasible to realize a technical requirement through a service. Additionally, it has to be verified that the customer allows the provider access to the product in order to provide the service. Furthermore, it has to be ensured that there are no legal restrictions that would prohibit the provider from fulfilling the requirement as a service. Once it is ensured that none of these causes would impede the implementation of a service solution the first task in Fig. 5 has been performed and the yes path is followed. If any of the causes impede the implementation the requirement cannot be fulfilled through a service and no comparisons in accordance with this method is necessary.

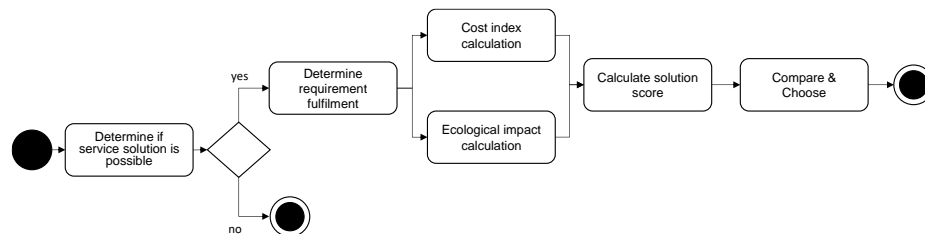


Fig. 5. Method for comparison of product and service solutions

The next step is to determine how well the different solutions full fill the requirements that the component has to satisfy. For this we will use an adapted and combined version of the technical valence and the decision matrix analysis. The first step is to create a list of a requirements the solution has to satisfy which will subsequently be scored comparatively. The requirements are separated into requirements that have to be fulfilled in order to achieve the desired function and optional requirements which also contain possible benefits. When the scoring is performed the scoring is always done as a comparison between both solutions. There are four different results that are possible one solution is substantially better than the other solution. One solution is slightly better than

the other solution. Both solutions fulfil the requirement equally. Lastly one solution fulfils a requirement the other one does not, this should only be the case for optional requirements.

Table 1. Requirement fulfilment matrix

	Solution 1	Solution 2
Requirement 1	2	0
Requirement 2	0	1
Requirement 3	0	0
Optional Requirement	-	0
Result	0,66	0,25

To determine the requirement fulfilment of both solution a matrix is created as shown in Table 1. If a solution is substantially better, it gets a 2 and the other solution a 0. If a solution is slightly better than the other solution it gets a 1 and the other solution a 0. Should both solutions satisfy the requirement equally both get a 0. In the case of optional requirements that are only fulfilled by one solution the solution that does not fulfil it gets a 0 for that requirement and the other one is left blank. To calculate the requirement fulfilment all individual evaluations for each solution are summed up and divided by the count of non-blank evaluations. These higher results is the solution that better fulfils the requirements.

After that it is necessary to determine the costs that are generated by either solution. When doing this it is important to consider all costs that will occur during the life time of the product, since service costs are likely to occur more regularly during the entire product life cycle and product cost are mostly incurred during the initial creation of the product. This means all initial capital expenditures necessary to set-up the solution are combined with all the costs that will be incurred during the operation of the product and are relevant to the solution. The solution with the larger sum is the one with the higher costs and therefore less desirable. Following that the ecological impact of both solutions has to be determined. For this the CEA introduced in section 2 can be used.

Now these three results are normalized and combined into one solution score. In order to make the individual values combinable they have to be normalized into one common range. For the requirements fulfilment we assign the best possible solution which is equal 2 to the number one 1 and the worst possible solution to 0. Therefore the results have to be divided by 2. For the cost we have to set the cheaper result to the number 1 as the best possible score. In order to reflect how much better the solution is we take the cheaper solution divided by the more expensive solution. Which results in the score value for the more expensive solution. Then the solution from the CEA has to be normalized to get the eco score that can be input into the solution score. This can be done following the same logic as for the cost index.

Lastly we can fill in the values into the equation 1 with representing the requirement fulfilment the cost index and the eco score.

$$s = \tau * r + \gamma * c + \varepsilon * e \quad (1)$$

As shown in Equation 1 the individual comparison results can be adjusted with a factor, and respectively which can be used to change the significance of either of the individual scores. If all scores are equally important, they can be just set to one. But if either of the score should be more or less important than the other, they all should be between zero and one. But the sum of all three should be one. Also, it is important that the factors remain constant during the comparison of two solutions. The solution scores are then compared and the solution with the highest solution score is the solution that should be chosen.

5 Case Study: Electronic sorting system

For the case study a sorting system for object carriers is chosen as a demonstrator. The sorting system, depicted in Figure 7, is used in a medical environment of a hospital pathology, where object carriers were sorted manually by a number from 1 to 1000. To relieve the laboratory staff, the sorting system was developed and manufactured by the Institute of Product Development. The object carrier is taken by a pneumatic gripper from one of four separators and is transported by a room portal to 1 of 1000 slots regarding its scanned number. Object carriers with no number are placed in a waste area. The movements and the usage of the room portal can be detected and saved on an external storage medium [25].

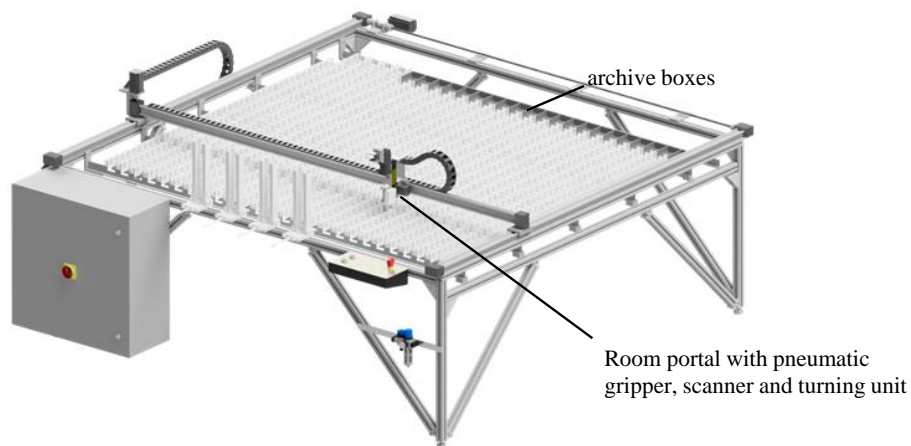


Fig. 6. Sorting system for object carriers at a pathology

The sorting system requirements are defined by the customers and the Institute of Product Development. Fixed requirements defined by the customers must be fulfilled by the product development. The following requirements are only an extract from the total list of requirements:

1. The sorting system must handle 2000 object carriers per day non-destructively;
2. The sorting system provide have 1000 slots;

3. The object carrier are taken out of the sorting system by laboratory staff into archive boxes.

These requirements from the customer are taken to the product development without knowing if the quantities are hold true during usage. Therefore, the Technical Inheritance is necessary to collect data and information about the usage and to concretize the requirements of the next product generation. Consequently, the usage phase is monitored and analysed.

5.1 Requirements for second generation of sorting system

During the usage of the sorting system all information about the movements, usage and all failures are digital detected and saved. The evaluation of the saved information takes place by an automated tool written in the programming language python. The results shown the actual usage of the sorting system and can be compared to the initial requirements. The comparison has shown that the old requirements can be concretized and new information and requirements are added by the costumer. The pathologists examine the tissue samples on the object carriers on two days a week at the same room, where the sorting system stands. Because of the need of complete silence the sorting system or an outstanding person is not allowed to work during this time. Also an outstanding person is not allowed in the room during the examination due to privacy reasons of the patients. The following requirements are only an extract from the total list of requirements for the second generation:

1. The sorting system must handle 670 object carriers per day non-destructively;
2. The sorting system must have 400 slots;
3. The object carrier are taken out of the sorting system into archive boxes without the interaction of the laboratory staff
 - a. The object carrier should be able to be archived at any time of day;
 - b. The object carrier should be able to be archived without any additional noises;
 - c. No additional space should be needed;
 - d. The error quote should be by less than 1%.

These requirements must be taken into account in developing a new generation of the sorting system.

5.2 Designs for the second Generation

The second generation needs to full fill the requirement that the object carrier are taken out of the sorting system into archive boxes without interaction of the laboratory staff. Based on the new requirements for the second generation two different designs are created. The first solution does not change the design of the first generation, but adds a service to take out the object carrier out of the sorting system into the archive boxes. The second solution changes the design of the first generation with additional technical components to fulfil the requirements.

The solution with an additional service contains a service employee, who comes three days a week to the pathology to take all sorted object carrier into an archive box by hand. The sorting system does not need to be changed or build new, but is used as it is. The employee with an hourly wage of 75 € drives 120 km in total from the service central to the pathology and back with an initial combustion car. On site, the service employee needs 15 minutes to prepare the equipment. He/she needs 30 minutes additionally to take all object carriers out of the sorting system and put them into the archive boxes.

The second solution takes the design of the first generation as a starting point, because not everything needs to be designed completely new. Only the areas for new requirements need be adapted by a technical solution. For the technical solution the original design is kept and only the room portal with the scanner and pneumatic gripper are changed, see Figure 8. Additional to the first design an electronic turning unit is installed. After every object carrier is sorted into the according slot the turning unit turns the grippers by 180°. That leads to the fact, that the second pneumatic gripper for object carrier stacks is taken to the first slot of sorted object carriers and takes the whole stack of one slot. The room portal takes the stacks to the back of the sorting field, where the archive boxes are installed. The swivel unit flips the second pneumatic gripper vertical by 180°, so the stack is placed in the archive boxes standing vertical. The technical solution archives the object carrier at the end of every day or as soon as the order for archiving is given. Because of the installed archive boxes within the sorting system, the dimensions are larger than for the first generation.

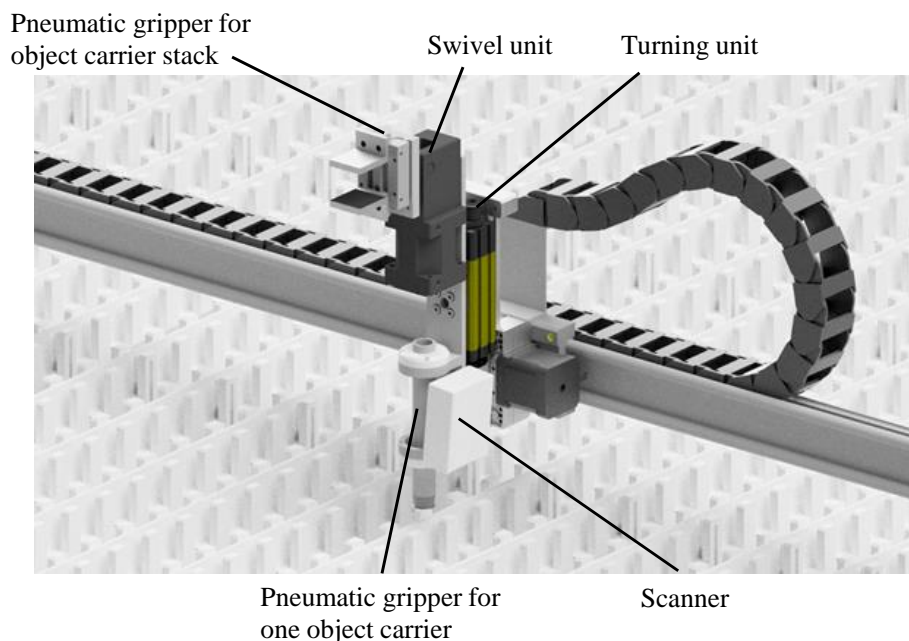


Fig. 7. Technical solution for sorting the object carrier stacks into archive boxes

5.3 Comparison of service and product solution

Both solutions need to be compared to decide which solution should be developed for the second generation. Therefore, the method presented in chapter 3 is used in for this case study.

Before the solutions are compare it is important to first determine if a service solution is even possible. The customer allows the provider access to the sorting system, however just on three days a week. Within these three days are no further legal restriction as long no patient information are shared with the service employee. The technical solution does not save or monitor any information about patients and can be used any time during a day. That leads to the fact, that a service solution is possible and can be compared with the technical solution.

The next step is to determine how well the different solutions full fill the requirements that the component has to satisfy. The requirements are listed above and are scored comparatively. Both solutions must fulfil the requirement that the object carriers are taken into the archive boxes without the laboratory staff. In addition, the object carrier should be archived at any daytime, which can provide the technical solution. The service solution cannot guarantee that the service employee is always available during the complete day. That leads to the result, that the technical solution fulfils this requirement better. The technical solution brings more pneumatic moving parts, which bring additional noises. The service solution is not completely silence but does not bring additional noises through pneumatic parts. This leads to a slightly better result for the service solution. The technical solution does need additional space for the archive boxes, which are installed into the sorting system. Only the service solution fulfils this requirement and gets a 0 and the technical solution is left blank. The requirements about an error quote by 1% is better fulfilled by the technical solution, because a service employee can be a bigger source of errors.

Table 2. Requirement fulfillment matrix for service and product solution

	Technical Solution	Service Solution
Object carrier are taken into archive boxes without staff	0	0
The object carrier should be able to be archived at any time of day	2	0
The object carrier should be able to be archived without any additional noises	0	1
No additional space required	0	-
Error quote less than 1%	2	0
Result	0,8	0,25

Next it is necessary to determine the costs that are generated by either solution. The lifetime of both solutions amounts to five years. For both solutions every 3 month a maintenance is needed. The maintenance costs for the service solution amounts to 1000 € per maintenance and the technical solution amounts to 1250 €, because of the addi-

tional mechanical and pneumatic parts. Over five years the mechanical solution generates 25.000 € maintenance costs, but the service solution generates 20.000 € maintenance costs. Additional to the maintenance costs come the initial costs for the technical solutions, which are 730 €. In total the technical solutions cost over five years 25.730 €. The service solution has also additional cost, which are caused by the service employee. The service employee with an hourly wage of 75 € comes 3 days a week in every week in 52 weeks during the year. Every year the service employee causes 8.775 € of cost per year and 43.875 € over five years. In addition, with the 20.000 € maintenance costs the service solution causes 63.875 € over five years.

The ecological impact needs to be determined by the cumulative energy analysis (CEA). Both solutions do not need to build a new sorting system but are using the existing one. The technical solution adds mechanical and pneumatic parts, which cause an additional power consumption of 0,1 kWh per day. The one-time installation of the parts results in a CEA of 46,64 MJ-Ep. During a working day the new parts causes 12,93 MJ-Ep. The employee drives 120 km in total from the service central to the pathology and back with an initial combustion car. On site, the service employee needs 45 minutes to prepare the equipment and to take all object carriers out of the sorting system and put them into the archives boxes. This results in a CEA of 593,61 MJ-Eq. for one day for the service solution.

Now these three results of the technical and service solution are normalized and combined into one solution score. For the requirements fulfilment we assign the best possible solution which is 2 to the number one 1 and the worst possible solution to 0. Therefore, the results have to be divided by 2. The score r for the requirement fulfilment is 0,4 for the technical result and 0,125 for the service solution. For the cost we have to set the cheaper result of the technical solution to the number 1 as the best possible score. In order to reflect how much better the solution is we take the 25.730 € of the technical solution divided by the 63.875 € of the service solution, which results in a score c of 1 for the technical solution and 0,4 of the service solutions. The ecological impact e is calculated the same way as the cost index, which results in a score of 1 for the technical solution and a score of 0,1 for the service solution. The factors, and are defined as 1, because all scores are equally important.

According to the equation (1) the Solution Score $s = 2,4$ for the technical solution and $s = 0,652$ for the service solution.

Table 3. Solution score

	Technical solution	Service Solution
Requirement fulfilment [r]	0,4	0,125
Cost Index [s]	1	0,4
Ecological Impact [e]	1	0,1
Solution Score [s]	2,4	0,625

Due to the Solution Score the technical solution is chosen for the further development.

6 Conclusion and Outlook

The goal of the paper to develop a method that can be used to compare technical and service solutions against each other and identify the preferable solution has been achieved. Which is demonstrated by the application of the developed method in the case study. The method considers three major factors in the comparative evaluation of product and service solutions. While the case study considers all factors are equally important an adjustment of any of the factors would have been easily possible. Furthermore, the used case study provides insight in how the proposed method can be integrated into the framework of technical inheritance. Additionally, this also shows how the data necessary for the calculation of the solution score can be obtained if a previous system generation already exists.

Even though the method considers the three most important factors it should be noted that the expansion of the proposed method is possible and should be the focus of further research. One of these additional factors would be the time to market which would not only impact the development costs of a product, but a shorter time to market can be an advantage in a competitive market. Furthermore, it would be prudent to expand the evaluation from a single PSS to PSS fleets. This is necessary to account for the fact that practical applications of PSS are rarely restricted to only a single PSS. For this a combination of the method shown here and the approaches discussed in [26], could be a path towards a solution taking both considerations into account. Additionally, it could be worthwhile to explore how multi criteria decision methodologies can be utilized to better model the relevance of the different criteria and their interaction.

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