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TOWARDS VALUE DRIVEN SIMULATION OF PRODUCT-SERVICE SYSTEMS: A CONCEPTUAL SCENARIO

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1. Introduction

Since the development of mass consumption and traditional product-oriented business strategies as a means for society's growth, the exchange of physical artefacts between a providing company and a receiving customer has for many years been a key mediator for customer value. The more products the company could sell, the more revenue it generated [Tan 2006].
In the last decade there has been increased interest and awareness among research community, industry and policy makers on the potential of Product-Service Systems (PSS), or functional-oriented business models; especially in order to make a shift towards a sustainable society [Mont 2002]. By this type of business model, the emphasis is on the 'sale of use' rather than the 'sale of product', with the intent of leading to a dematerialization and life-cycle view of the entire production and use system, hence having possibilities to achieve sustainability goals.
In literature review of opportunities and challenges of the PSS business model are available. Benefits from a producer perspective are; opportunities to deliver a higher value offer and to provide a more differentiated and customized offer, and from the customer side; the possibility to receive higher and 'suited' values at lower prices since the ownership is now on the producer's hands. For society this approach increase the chance to provide benefits for people while reducing the environmental impact.
Shifting from traditional business model to PSS requires new definitions of value [Tan et al. 2006] as well as new methodologies for taking it into account within product development. Furthermore, since its recent development and its characteristics of new paradigm as business model, it requires for a company new and increased innovation capabilities.
The implications for design and development, when using a PSS frame, are; making the correct choice in the preliminary design phase impacts the entire product life cycle in an order of magnitude that could span from making the product being a success, to generating, instead, a total business failure [Browning 2002]. This statement gains more and more relevance when the product is characterized by a long life-cycle, when the technology is highly capital-intensive and when later life-cycle modifications imply huge expenditures in terms of money and labour. In the effort of being competitive in the globalized market, a common and intuitive strategy for companies is to cut costs while increasing structure efficiency [Stahl 1997]. However, this approach does not always lead to success. Cost competition does not ensure long-term value added, because of the real risk of engaging in a cost-based competition against market followers [Lewitt 1966]. So far, what becomes a real target to any company who wants to lead, or keep on leading, the market, is to provide the highest value to the system in which the company is competing. This concept should be considered not only from the final product seller focusing on end user, but also by all those companies that are relevant business

partners in the supply chain. Collopy [Collopy 2009] stated that for a product to be successful it should maximize the value generated for the customer and for the system; how the profit is then divided between companies is instead decided by the market.

The question that arises seems natural: *how can a company re-define its consideration of value provided when meanwhile increasing its innovation capabilities in order to "jump into" the new paradigm, and how can early design phases of PSS be treated*?

2. Objectives

The main objective of this paper is to discuss existing challenges when considering value in PSS conceptual design and the potentials of using a value simulation approach as a means to succesfully deal with the wider design space that such a business model implies. Furthermore, a conceptual scenario based on a case is presented in order to strengthen the paper and provide a base for further development.

3. Research methodology

The approach emerges from the analysis of real industrial problems together with theoretical studies on the corresponding phenomena. The initial problem statement has been defined in collaboration with a Swedish automotive manufacturer and its supply chain of some 30 partners.
However, the research approach has been a literature review of current practices of value driven simulation in conceptual design, both in traditional product development and in PSS; and by workshops run with project teams, and students, that framed the example presented in this paper.

4. What is the problem: Value consideration in PSS developement

The highest possibility for the designer to improve artefacts in order to increase the business's success probabilities relies in the early phases of development. In an ideal scenario, companies should always select design concepts able to increase the added value for their customers and stakeholders. Being able to calculate a priori, in a transparent and repeatable way, the value of a given solution is, however, not a straightforward process. As stated by Anderson and Narus [Anderson and Narus 1998] remarkably few firms have the knowledge and capability to actually assess value and, by consequence, gain an equitable economic return for the value delivered to customers, and this especially becomes a problem in the preliminary design stages [Browning et al. 2002].
Lindstedt and Burenius [Lindstedt and Burenius 2006] argue that the creation of an unrivalled customer value leads to a Business Success. They define customer value as:

$$\text{Customer Value} = \frac{\text{Perceived benefits}}{\text{Total expenditure}} \quad (1)$$

The model proposed by the authors is divided into three processes. The project has to create value by (ibid.):

- Maximizing the business opportunity (result: the contented sponsor)
- Developing products with unrivalled customer value (result: the satisfied customer)
- Deepening relationship and knowledge (result: the successful team)

The same conclusion is drawn as well by Allee [Allee 2000], that argues that the partners involved in a business (provider, supply chain, customers etc.) exchanges value in three "currencies":

- Goods, services and revenue
- Knowledge: Exchanges of strategic information, planning knowledge, process knowledge, technical know-how, collaborative design, policy development, etc., which flow around and support the core product and service value chain)

- Intangibles: Exchanges of value and benefits that go beyond the actual service and that are not accounted for in traditional financial measures; such as sense of community, customer loyalty, image enhancement, co-branding opportunities

The author also highlights that in the business there is always ***value provided*** and ***value returned*** between the actors. For example, providing a service to a customer a company may get feedback about the service itself, so enhancing the know-how about it.
Even though these can be considered as a too general definitions from a practitioner perspective, they can be used as a base to discuss what kind of values a company needs to focus on; and what should be the main pillars that a corporation should be based upon.
In order to clarify what the main issue is when considering value in the design of PSS solution, a little discussion about how products are developed in industry is necessary. Even if hybrids exists, the common framework for product development management is the Stage-Gate® process by Cooper [Cooper 2008]. In this framework the process is divided into *Stages*, where the product development team performs all the activities necessary to the development of the product; and the *Gates*, where the project is reviewed by decision makers that has to take decisions about if the project can go ahead, what is rejected, and what needs to be reworked. This paper is particularly focused on the preliminary phases, thus Stage-Gate 0, 1 and 2, when the preliminary ideas are discovered, sorted out and when at the end several product concepts are built upon.
What usually happens is that decision makers, having detailed analysis in order to consider costs/risks of the concept but lacking of informations about the benefits provided by the radical concept (such as customer loyalty, cost cutting opportunities in the future, brand image etcetera), often unintentional "kill" the idea with the most potential for creating a unique selling point for the company, and to overtake the competitors in the challenge. [Chesbrough 2003] This since something new never pass the requirements analysis that matches the exisiting solution. Hence sub-optimizing existing soultions always have the upper hand on new solutions, because the evaluation criteria are set in such a way.
This happens particularly when designing a Product-Service System solution, due to the relatively recent development of this type of business model, and lack of evaluation mechanisms for PSS.
So there are highest risks nowadays for the PSS solution to be "killed" in the early decision gates, preferring more conservative but eventually less successful solutions.
Isaksson et al. [Isaksson et al. 2009] argue that the innovative concept of PSS requires a higher integration of product aspects as well as service aspects in the design process, in the past designed independently between each other. The authors highlight also the need to involve more the customer into the design process, a global development with partners and suppliers as well as modelling and simulation of all the PSS aspects early in the design process. Moreover, the need for new methods and tools in order to model, simulate and communicate value in the early design stages is considered a key factor in order to design successful PSS solutions.
After considering these aspects, can then be concluded that the problem is that the companies know already that they should provide higher value for the customer, and that they should consider value in a broader perspective in order to achieve benefits in a longer timespan, and that new methods and tools are needed.

5. Possible solution: Value Simulation approach

The Value Driven Design (VDD) concept grew after almost 50 year research quest on Systems Engineering mainly around the Aereospace industry [Collopy 2009]. The main objective of the approach is that engineers should select the best design from a value perspective, rather than the design that "merely" meets the requirements. In the framework there is no requirement set a priori, neither on a system level nor on a component level, instead an objective function is given to the design team, which converts the set of design attributes into a score. The design team is then asked to develop the design that provides the higher score.
The main benefits stated by the developers of the approach are: it enables optimization, since the focus now is on o find the "best design", where a higher score indicates that the design is best; it prevents

Design Trade conflicts and it avoids cost growth and performance erosion, since the approach enables a system optimization rather than a local optimization driven by the strive of meeting requirements.
Even though the approach is quite new in literature, interesting industrial cases have already been made.
Curran [Curran 2010] presents a case when Value Driven Design is used in order to address the structural configuration for an aircraft fuselage panel. The work focuses on combining design parameters and operational value, such as direct operational costs and manufacturing costs. The case demonstrates the application of VDD in terms of an aircraft manufacturer's profit.
Another interesting approach is proposed by Bertoni et al. [Bertoni et al. 2011] The idea is mainly to use qualitative scores to assess the value of design components, in the specific case within the aerospace sector. The approach uses baseline values (value that a component at least needs to fulfill) and target values (highly ambitious values that the component might have). The idea is then to communicate value through color coding integrated in the copany's CAD system. Even though the approach is very interesting, the authors highlight the need of quantitative "back-up" data for the value calculation in order to give reasoning to make trade-offs during the different decision gates.
The preliminary analysis of current methodologies has shown that interesting approaches on value simulation and communication are available. Mainly they can be considered divided into three categories. For value simulation; approaches that try to model value using mathematical functions composed of partial differential equations and qualitative approaches in which the team has to define baseline values and target values, and when it is the team itself that decides the value of a certain concept based on its experience and knowledge. For value communication, the authors have found the approach of using color coding systems integrated into CAD models interesting.
However, these approaches are still in a development phase, and the authors consider that probably a combination of them will be the best solution in order to achieve good results in the current project.

6. Value modeling of Product-Service Systems

In order to build a model for the assessment of value in early product development a preliminary classification of what constitutes value for a company is necessary. This section propose a classification that has been made after an extensive literature analysis, and the description is followed by the references taken as base for the rationale.
However, this framework is not intented to be an "operative" classification of value, since it is still too general. The company itself must decide what parameters might increase the value provided, according to its strategies, market, competitional environment. Furthermore, a preliminary and general classification of what constitutes value is necessary in order to provide a base for the discussion around the value provided by a Product-Service System offering.
The proposed model is based on the equation (1) and the authors divided value into five dimensions (or "currencies"): two for the "denominator" side, and three for the "numerator". Regarding the latter, the authors devided benefits following the "value model" proposed by Lindstedt and Burenius [Lindstedt and Burenius 2006], seeking what benefits are considered as value by the three main actors of a PSS project: the sponsor, the customer and the development team.
This section has the purpose also to describe them more in detail, to give a rationale in order to explain the reasons for their inclusion in the model, and how a PSS can increase value along these dimensions.
As will be argued in detail in the next paragraph, methodologies in order to considered costs, risk and revenue have been consolidated during the past years in both research and industry environments. Therefore, these will be tretead briefly in this paper, citing only main reference methodologies developed in the area. Attention and discussion will instead be dedicated to intangible value perceived by the customer and the knowledge gain achieved by the company, since a lack of research still exist and that will be the authors' main future work.

6.1. Cost, risks and revenue evaluation

The cost and revenue evaluation is probably the most well defined part of the equation (1). In industry many methods are broadly applied. Among the most used are the cash-flow analysis, the net present

value, adjust present value, and internal rate of return calculation, just to cite a few. All these tools are very useful and mainly these analysis are conducted by finance departments and cost managers.
These methods have been rather consolidated over the past fifty years, and different methods has been developmed in order to plot costs and revenues over the product's lifetime. Among the most used, it is possible to cite the return map.
Naturally, the risk associated to a product concept is a important factor that must be assessed during the preliminary design phase. Literature presents different methodologies in order to estimate risks in early product development. Bertoni et al. [Bertoni et al. 2011] summarizes the most used methodologies developed during the last decades, and can be used as a reference for a deeper investigation.

6.2. Intangible benefits perceived by the customer

For intangible benefits is meant all those benefits the customer perceives as value but not strictly related to any intrinsic value or no material being. They are not easy to define and formulate. Some examples are customer loyalty, sense of community, brand image, co-branding opportunities.
A Product Service System solution can in theory reach great opportunities for intangible value such as Customer loyalty. This type of business model can enhace a more trustwhorty relationship between the customer and the provider.
Steiner and Harmon [Steiner and Harmon 2009], highlight how increasing the customer's perceived intangible value can positively affect the business's level of success. The authors also divide the intangibles into three categories: Knowledge (related to the customer's perception of the company and its products), Emotions and Experience. They provide also a good taxonomy on how these values can be divided in sub-categories. Even with a rather clear definition of what constitutes intangible value, the authors highlight the current lack of how intangibles can be considered in product development and positively evaluated by managers and decision makers.
However, the paper divides customer value into three layers: Product layer, Service layer, and Intangibles layer. Even though this classification is quite common, in our opinion when considering the customer perception of a product it should be considered always from the intangibles' perspective. This is true even in traditional product context, considered as merely tangible by many authors. Almost all the values perceived by the customer are intangibles. For instance, how much do we buy a watch just because it will tell us the time? Or do we buy it because we like its design or because we recognize its brand?

6.3. Knowledge gain

For knowledge is meant all the exchanges of strategic information, planning knowledge, process knowledge, technical know-how, collaborative design, policy development, etc., within the company and between all the partners of the value chain involved in the product development process. [Alee 2000]
This parameter is seldom considered, but extremely important in order to increase the knowledge "wallet" of the company to increase the possibility for cutting cost, gaining innovation cababilities etcetera. This is becoming extremely important in the recent years when the tendency is to more and more first tier and second tier supplier into the product development process.
This is particulary experienced by the authors in the current project, that is developed in collaboration with some 30 companies, suppliers of a Swedish car manufacturer. In some cases, these suppliers do not have research & development department (due to the dimension of the company) so that they considered really an added value to gain knowledge by the development's activity.
The potentials for knowledge gains are especially high when designing a PSS. In fact, when changing the ownership from the customer to the Original Equipment Manufacturer (OEM) the latter is motivated to design a solution in a long-term perspective, having time to continuously improving the solution, and also having continuously feedbacks from the customer, due to the more trustworthy relationship between the partners.
As well as the intangibles values perceived by the customer, also knowledge is a benefit still difficult to assess and evaluate in the early stages of the development process.

One interesting approach to deal with knowledge transfer in product development is the Knowledge Maturity scale proposed by Johansson [Johansson 2011] Even though the scale is intented to deal with the problem of how much the decision maker can "trust" the different design solutions proposed by the team, one interesting opportunity seems to integrate such a scale into the value simulation approach. In this way, the simulator can give a score on how much knowledge will be gained by the company with that particular concept (i.e if we include a "customer help us" feature to continuously improve our the software we offer to the customer).

7. Conceptual example: Value simulation into practice

In order to provide an example on how Value Driven Simulation could become an approach when dealing with Product-Service System development, a conceptual case is presented. Although the authors have tried to be rather accurate in order to provide a good base for the discussion, the present example is based on gross assumptions, and it cannot be considered a representation of a real industrial case. The example has emerged from discussions and workshops with students and industrial partners in the automotive supply chain project.

7.1. Example presentation

The example presented is based on a car sharing system. Let us consider the case of a car manufacturing company that wants to move from manufacturing and selling cars towards a car sharing system, in which the company manufactures the cars it needs and then it provids a "total system offering" being responsible of filling fuel, maintenance of the cars etcetera. (the slogan in Swedish is moving from "köp en bil", buy a car; towards "köp en mil" buy a Swedish mile, 10 Km).
With the students it has been decided to skip the part of customer identification, deciding a priori to take as customer target young middle-class Swedish singles or couples, with a possibility to spend for transportation by car less than 500 SEK (ca. 50 €) per month.

7.2. Preliminary Value model, main assumptions and data gathering

The preliminary Value model follows the approach adopted by Curran et al. [Curran et al.2010] using a differential- additive valuation manner. As stated by the reference, it is more reasonable to relate the value of one design option to another, rather than trying to measure an absolute value. Furthermore, there is a need to normalize parameters that otherwise, because composed by different units of measure, will completely blow the result, making impossible any comparation between options.
In the example the value levers that have been decided to incorporate are presented in equation (2) and consist of: ***profitability*** (revenue-costs) and ***customer experience***.

$$dV = \alpha_{profit.} \sum_{i=1}^{Ni} (w_i \times d\left(\frac{profitability_{i1}}{profitability_{i0}}\right)) + \alpha_{cust.exper.} \sum_{j=1}^{Nj} (w_j \times d\left(\frac{cust.experience_{i1}}{cust.experience_{i0}}\right)) \quad (2)$$

Where the parameters $w_{i,j}$ are the weights by which the design team decides to allocate more importance according to experience, competitive market etcetera. i, j are the different dimensions that composed the single value lever, also decided by the design team. The concept will be clearer throughout the example. $\alpha_{profit.}, \alpha_{cust.exper.}$ are the weights given by the team to the overall value lever, in other words how much that value lever added value to the general system. For the sake of simplicity, it has been decided to place the two weights of 1. As previously stated, the value of every configuration is related to the value of a benchmark option, indicated in the equation with the subscript 0. As benchmark, the authors decided to adopt a Toyota Corolla used in a car sharing case in Sweden, which was possible to gather some data by Zhang [Zhang 2008]. Other data have been collected from the manufacturer's website, and other data about car sharing system has been collected through websites using Car sharing companies in North America.
Without going deeper into the calculation, ***Profitability*** has been valuated by the difference of revenue, Direct Operative Costs (only Fuel Cost), Cost manufacturing and Costs of Maintenaince. Since this calculation has been considered correct out of the assumptions made, the value lever will therefore just one, and the weight will be considered 1 for the sake of simplicity.

The ***Customer experience*** lever has been valuated according to five dimensions, taken after a Kano model analysis with the students and with the weights given empirically accordingly to the importance stated during the discussions.

- Price/Km: the cheaper it is, the higher means for the customer, w=8;
- Must-be requirement: warmth in the sitting system, w=1
- Performance requirement: the bigger is the sitting area, more important is for the customer (considered as means for comfort), w=2;
- Satisfaction requirement: the bigger is the baggage area, the better it is for the customer (since the students considered that one main use of car sharing might be transporting furniture or other equipments for the users), w=3;
- Risk that the car brakes during one travel: the higher is the risk, the lower is the value added to the system, w=5;

Regarding the latter, the risk has been grossly considered inverse proportional to the weight of the car, when the weight has been considered the main means for robustness. The higher is the weight of the car, longer will be the Mean Time Between Maintenance (MTBM). So, in other words, the lighter is the car the shorter will be MTBM (with of course an impact on Costs of maintenaince), but also with a higher risk of making customer unhappy with a less robust car that eventually will breake during the trip. MTBM has been one of the main assumptions by the authors. It has been considered merely depending linearly by the weight of the car, and calculated linearly from the MTBM and the weight of the benchmark car.
The equation for the customer experience Value lever is then:

$$dCust.exp. = 8\times\left(\frac{(Price/Km_0)}{(Price/Km_1)}\right) + 5\times\left(\frac{Weight_1}{Weight_0}\right) + 3\times\left(\frac{A_{baggage1}}{A_{baggage0}}\right) + 2\times\left(\frac{A_{seats1}}{A_{seats0}}\right) + 1\times\left(\frac{T_{comfort}\times A_{seats1}}{T_{comfort}\times A_{seats0}}\right)$$

7.3. Conceptual scenario: Value Driven Simulation

Due to the dimension of the paper, it is not possible to clarify all the assumptions made in the model (that, once again, are many but accuracy esule to the scope of the example). The authors decided to maintain similar all the parameters between the benchmark concept and the options, and to change only four parametrs: $Price/Km$; s length of the sitting system, b length of the baggage, $weight$ weight of the car. The timespan has been considered along 8 years, with the hypothetical case of one year of manufacturing all the cars that will then use along the timespan, with regular maintainance every MTBM. Table 1 presents the simulation of four different design options in terms of added value.

Price/Km (€/Km)	s (mm)	b (mm)	Weight (kg)	**dV**
0.35	1200	1300	1500	17.73
0.2	1000	1200	1700	19.94
0.5	1100	1400	1800	18.35
0.22	800	800	1200	15.71

Table 1. Value simulation using four different configurations

By the simulation it can be seen that providing a cheap but rather "robust" car (second row) is the best design option out of the four configurations taken into account (even though in the model important parameters such environmental impact, cost of resources has not been modelled). Another interesting reflection might be in the third case, if we provide a good customer experience, price eventually will not considered so important. Or opposite, in the fourth case, a cheap but "ugly-not functional" car (and not so robust, so with high risks that it will abandon us on the way) is not the best design choice either.
It has also been simulated the value added to the system by modifying for instance $Price/Km$ and $Weight$, maintaining all the other parameters unchanged, using MATLAB. Figure 2 shows the results

of the simulation. It is then possible to see area of interest in terms of value added to the system. Figure 1 presents the results of the simulation.

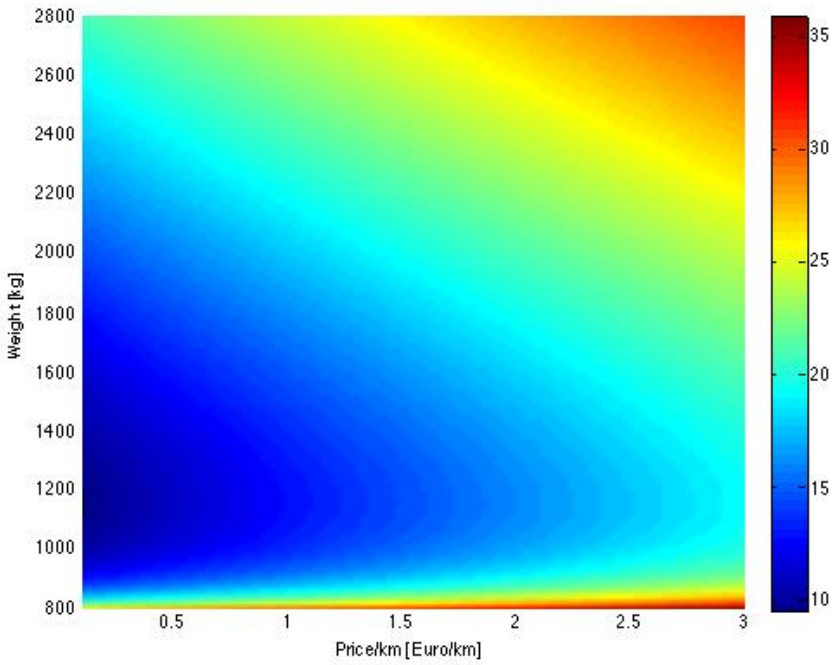

Figure 1. Value simulation depending on Price/Km and Weight

By the simulation, the design team can highlight potentially good design options together with business considerations (i.e the area in the corner down to the right seems interesting by the simulator, but totally out of the customer target taken into focus) or technical requirements (the team can decide that it is imposible to provide a safe car under 1000 kg). For instance, the team might see that if they want to remain around 1800 Kg and with cheap price, then it is better to increase weight (and so robustness); that will maintain the company profitable but also will provide a better customer experience, since the risk of technical failure during the travel will be lower. With more complex models than the one presented on this paper will also be possible to show areas of local optimization between business parameters (such as price) and parameters depending on design (such as weight).

6. Conclusions and future work

The paper discussed potentials and existing challenges of considering Value when designing a Product-Service System offering. The main problem has been identified on having new methods and tools that can help designers to consider every design option from a value perspective (possibly based on a longer timespan). Nowadays mainly revenue, costs and technical risks analysis are taken into consideration and boiled down into monetary terms in a rather short period. This often caused the "killing" of more radical ideas (that could potentially bring more benefits if seen in a longer time perspective) at the various decision gates during the project. So at the end, everybody talks about value, but actually money is what people look at in the end.

The paper discussed how a Value simulation approach can provide benefits in terms of compared different design solutions from a Value perspective. With such an approach it is possible to take into consideration the value of aspects like intangibles perceived by the customer (provide the best customer experience as possible) or knowledge gained by the company during the business. An example has been presented in order to discuss how Value simulation can be effectively a strength when dealing with the wider design space that the PSS development implies. Another main benefit is that such a tool will enable engineers to have at least "reasoning" in order to sponsor more radical concepts. Thirdly, the tool can enable optimization and increase innovation, since the team can look at

why the model has low value in a certain lever, and starting to brainstorm possible solutions of how to increase it.
However, the approach is still in its infancy and future work needs to be done. First of all, the weighting phase is crucial since it will profoundly affect the model. Further research will focus how the design team can place define weights in a qualitative but effective way, in order to take the major benefits from a "lightweight" qualitative approach and the simulation based on mathematical equations.
Secondly, work has to address how intangibles and knowledge can affect monetary parameters, such as the price of the offerings or costs (making the intangibles tangible, so to say). This will require further research, but it has been seen as a great opportunity of making a step further in the topic, since the uncovered areas realted intangibles and knowledge are still many.

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