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Risk Assessment of Innovation Prototype for the Example Hydraulic Cylinder

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Abstract: This paper presents both an example of the innovation prototype risk assessment and the universal way of conduct in assessing such solutions. For this purpose, the authors proposed a prototype risk assessment method based on the assumptions of the SWOT and TOWS analysis and the multi-criteria technical innovation risk assessment method. In the assumptions of the developed method, an account was taken of the conclusions resulting from the prospect theory. A symptom of this action was, e.g., a characterization of the team of experts (working on the prototype) in terms of their individual personality traits and mind (which has not been used so far in practical methods of assessing risk). As a result of the conducted assessment (for an innovative hydraulic cylinder prototype), the innovation prototype risk was determined as low, which was presented both on the map of domination and the map of risk assessment for this prototype. The procedure presented in the paper was planned so as to ensure that, after the prototype moves to the commercialization phase, it will be possible, on the basis of the already made calculations, to apply the full risk assessment dedicated for technical innovations with ease. This gives it a universal nature.

Keywords: risk assessment; innovation; SWOT analysis; prototype; hydraulic cylinder

Citation: Deptuła, A.M.; Stosiak, M.; Deptuła, A.; Lubecki, M.; Karpenko, M.; Skačkauskas, P.; Urbanowicz, K.; Danilevičius, A. Risk Assessment of Innovation Prototype for the Example Hydraulic Cylinder. *Sustainability* **2023**, *15*, 440. https://doi.org/10.3390/su15010440

Academic Editor: Danail Hristozov

Received: 8 November 2022
Revised: 17 December 2022
Accepted: 20 December 2022
Published: 27 December 2022

1. Introduction

Risk is a phenomenon that accompanies every action. It is defined as a deviation from the assumed state. The risk may involve both a positive and negative deviation, and this reflects two basic risk concepts generally referred to as the negative and neutral risk concept. In the negative concept, the risk is perceived as a hazard or danger of an undesirable event. In the neutral approach, the undesirable event is balanced by the possibility of not achieving a positive effect. Therefore, two states may be present: threat or opportunity. In the first case, a deviation from the desired state results in positive effects, and in the second one, negative effects that are not beneficial for the decision maker. The neutral concept appears when the result of the given event (action) is not known [1–9].

Risk assessment is an element of analysis related to risk measurement. It consists of quantifying, namely assigning measurable features to particular threats. Most frequently, the risk is calculated as a product of the probability of the occurrence of the hazard and its effect. Such an approach is adequate, e.g., for insurance, and is also used in the innovation risk evaluation [6–12].

There are many definitions of innovation, but each of them should always be based on invariable elements, these being the need for practical application and the sense of novelty resulting from the first use in a particular space (community, company) to achieve specific social and economic benefits. For the present paper, the term innovation thus refers to each idea converted into a specific action/thing, which is characterized by an intentionally designed change incorporating novelty both in the strict and in the broad sense, which, by definition, is to bring certain benefits. To use this term, it is also necessary for the particular solution to be practically applied [7,13–16]. Many classifications of innovation can be found in the professional literature. It seems that the most frequently used division is one presented in the Oslo manual, which divides innovations into four basic groups: product, process, organizational and marketing ones [17–23]. In production enterprises, the category of technical innovations, which relate to technical and technological changes in the organization, is important [24]. Most frequently, they involve product innovations resulting from introducing new products or improving the already existing ones as well as process ones, namely resulting from the introduction of new methods of manufacturing or using the existing goods.

The purpose of this article is to assess the risk of an innovative hydraulic cylinder prototype. Thus, this is an example of a technical innovation prototype. The assumptions of the SWOT/TOWS analysis, being one of the methods used to identify the risk factors, were used in the presented assessment. In addition, due to the innovative nature of the prototype, the basic assumptions of the multi-criteria technical innovation risk assessment method were also used, presented, e.g., in the works [24]. Therefore, the indirect goal was also to develop a risk assessment method dedicated to innovative prototypes. Due to the rapidly changing environmental conditions, the prototype risk assessment has presently become necessary and still needed ahead of the decision itself to start production. The prototype of an innovative hydraulic cylinder was made of carbon fiber-reinforced epoxy with a nanocomposite layer to ensure proper conditions of cooperation between the piston and the internal surface of the cylinder [25]. The use of modern materials such as plastics [26] or composite materials [27,28] is a strong trend in the development of hydrostatic drive components.

Risk assessment of a prototype innovation can be a milestone in the development of a new product, so it should be carried out even before the commercialization of research results. The literature on the subject presents a concern for the risk assessment of innovations. However, before the project/prototype passes the testing phase, it may turn out that its commercialization is not profitable. Few studies deal with risk assessment in product creation and development [29]. The need to develop this area of research can also be found in the work [30]. The authors emphasize the need to adapt existing methods for evaluation at an early design stage which, unfortunately, has not been effectively developed to date. The authors of this paper noticed the need to develop a method dedicated just to prototypes to avoid costs and waste of time spent on potentially ineffective actions. It will be an important contribution to the development of innovation management theory but also to applied research as a concrete scheme of conduct in the case of risk assessment of innovation prototypes.

The structure of the paper is as follows. The presented literature analysis is mostly applicable to an overview of the risk assessment method, the assumptions of the multi-criteria technical innovation risk assessment method and assumptions of the SWOT/TOWS method. Then, the authors present their research, within which the assumptions of the proposed prototype risk assessment method. In this part, the procedure of conduct is also presented. In the next part of the article innovation, the composite hydraulic cylinder prototype risk assessment was conducted. The final part of the paper is the results and the discussion related to the obtained risk assessment. The summary of the paper presents basic advantages and disadvantages resulting from the application of the proposed prototype risk assessment procedure are presented.

2. Review of the Literature

2.1. Overview of Risk Assessment Methods

Many methods of risk assessment can be found in the literature. Methods in the scope of project management are currently used in the innovation risk assessment. The most commonly used quantitative methods for risk assessment are related to the methods of [14,31–38]:

- Strategic management;
- Statistical;
- Operational research;
- Financial.

Strategic management methods are based on creating scenarios of the assessed object/product/activity. An extensive group of methods is statistical methods, where the following methods are used for risk analysis: analytical method, probability analysis, Bayesian network or analysis of variance or standard deviation. In the area of operational research methods, we can mention, for example, decision tree analysis, simplex algorithm, GERT method, Monte Carlo method and simulation method. Financial methods are the basis for the analysis of financial risks associated with the method of project financing [33].

An extensive group of methods is represented by behavioral models that use the knowledge and skills of the expert [36,39–42].

The literature provides numerous examples [41,43] in which the way of perceiving reality influences human opinions and beliefs. An example of a solid theory in the field is the assumptions of the prospect theory [42–45], which clearly indicate the connection between the person of the expert with the decision-making process [46]. The authors also frequently use fuzzy logic for the risk assessment process [35,46,47].

However, a comprehensive approach to the prototype of innovation risk assessment is a gap in the research concerning innovation. This area became a determination of the development of the risk assessment method dedicated to the prototype of innovation for the authors of this paper. What is more, the academic literature focuses mainly on economic risk factors, however technological.

2.2. Technical Innovation Prototype Risk Assessment—Theoretical Foundations

For technical innovation risk assessment, the use of the two-stage multi-criteria assessment presented in the paper is suggested [24]. The presented assessment procedure is connected with the negative concept and involves the determination of general and detailed risk. Within the first assessment, the experts determine the threat to the innovation within five general criteria, which characterize the company, the innovation and the innovative solution being evaluated. The detailed assessment is a more complex stage during which the threats associated with the given innovation are assigned to fourteen detailed criteria.

In the literature, most of the methods used for risk assessment are expert-based. Differences between experts' opinions significantly affect the outcome of the assessment, therefore there is a need to continuously improve and objectify such methods [29].

2.3. Theoretical Assumptions—SWOT/TOWS Analysis

The SWOT method originates from the analysis force field concept by K. Lewin, developed in the 1950s. It owes its name to the first letters of English words: S (Strengths), W (Weaknesses), O (Opportunities) and T (Threats). Its simpler version (which uses the same analysis scheme) is presently applied just under the name SWOT/TOWS analysis, where the TOWS analysis is the reversed SWOT analysis. A simplified version of this method simultaneously accepts—unlike Lewin's concept—large freedom in selecting the techniques and procedures (tools) used to determine the different factors being part of the examined analysis area. The essence of the SWOT analysis is distinguishing the strengths and weaknesses as well as the opportunities and threats of the project. This stage of the analysis is used in the threat identification process. However, it should not be forgotten that finally the SWOT analysis is used to determine the business operating strategy. As a result of conducting it, one of the four action strategies can be determined [48]: competitive, aggressive, defensive and conservative.

Strengths and weaknesses are internal factors of the company that the managers are principally able to control (sometimes only to a limited extent). On the other hand, opportunities and threats are factors that are beyond control, which the organization must adapt to. The proper identification of the factors from these four areas allows the company to plan the respective action strategy [49–52].

The main advantage of the method is its simplicity, contributing to its widespread use. However, its application involves certain disadvantages, mostly including subjectivity in conducting the analysis as well as a limited list of factors. It is a qualitative method, with its modifications being quite numerous, mostly to the extent of the combination with quantitative methods. Its modifications, such as the Analytic Hierarchy Process (AHP)-SWOT [53–55] and the Analytic Network Process (ANP)-SWOT [56], which make SWOT factors commensurable regarding their relative importance, are known [57].

3. Risk Assessment Procedure

3.1. Research Assumptions

However, it is more and more often necessary to assess risk still at the pre-production stage; therefore, the authors decided to use certain assumptions presented in the technical innovation risk assessment method [24] to evaluate the innovation prototype risk. The adapted elements are general assessment criteria [24,58]:

- CG.1.—The scale of the innovation prototype that determines the accessibility of the particular solution on the market. It was assumed that prototypes on the scale of the world will be less risky than those made within the company due to the economic viability of future innovation;
- CG.2.—The period of technology application in the world is the time that has elapsed since the first emergence of the technology used in the prototype. It was assumed that a project is riskier when the related technology is used worldwide for less than one year. This results from the assumption that it is still not finally verified/tested in terms of the chances for technical success;
- CG.3.—The period of project implementation that is directly related to the assessment of the prototype costs. The longer the completion time, the higher the costs of such a project, and at the same time, the higher the risk related to the life span of the particular solution on the market. Therefore, it was assumed that the risk is higher when the project implementation period is longer.

In the innovation risk assessment, selected elements are part of the general assessment. In the case of innovation prototypes, the assessment will not be divided into general and detailed; therefore, three selected elements will be considered at each stage of the SWOT/TOWS analysis. These criteria will be treated as a constant element, taken into consideration in determining the interactions between the particular criteria. Due to the constant nature of this assessment element, weights will not be assigned to these criteria, as in the case of the other criteria. Advantages, disadvantages, opportunities and threats will be variable elements (depending on the innovation prototype being evaluated), and it is within them that the risk factors concerning the assessment of the prototype risk will be determined.

In addition, since the assessment is concerned with the prototype, the neutral risk assessment concept was used in this case.

A fundamental change as compared to the proper innovation risk assessment [24] is the use of the neutral concept. It is justified from the point of view of conducting an additional risk assessment still in the construction phase. This proposal results from the fact that, in the prototype stage, it would hardly be justified to adopt assumptions concerning the effects being only negative in nature. In fact, the prototype is in the phase of testing, and this state of affairs persuades the authors of this work to choose this concept. To this end, the SWOT/TOWS method selected for risk assessment will be ideal.

Consideration for the elements resulting from the prospect theory will be the case within the analysis of personality traits and the mind of the experts developing the prototype [43–45,59–62]. For this purpose, the experts completed the so-called inventor's behavior questionnaire (IBQ) [63]. On its basis, the importance of particular assessments that individual persons had conducted was determined.

The idea behind the SWOT–TOWS method [64–67] is also partly subject to adaptation to the innovation prototype risk assessment. A result of the completed analysis risk on a four-degree scale, which originally corresponded to the company's operational strategies, will be determined. Obtaining information about four possible risk levels will be possible from the innovation prototype risk evaluation:

1. Low ("State of SO domination");
2. Medium ("State of WO domination");
3. High ("State of ST domination");
4. Very high ("State of WT domination").

A result of the SWOT and TOWS analysis will also be the identification of the current "state of prototype domination" [48,68]:

1. "State of SO domination" (strengths–opportunities")—the aggressive strategy, otherwise called maxi–maxi, will correspond to low risk due to the domination of prototype strengths and opportunities. This is the most favorable situation in which attempts should be made to finalize the production of the prototype;
2. "State of WO domination" (weaknesses–opportunities")—the competitive strategy, otherwise called mini–maxi, means the advantage of opportunities over threats with the domination of project weaknesses. However, the prototype implementation proceeds in a favorable environment, which slightly minimizes the risk and allows us to call it medium;
3. "State of ST domination" (strengths–hazards)—the conservative strategy defined as maxi–mini corresponds to high risk. Despite the strong internal potential mostly related to the project concept, there is a large number of external threats that potentially place the project in a very high-risk area. In this respect, attempts should be made to maximize the use of own strengths and, with their help, minimize the external threats;
4. "State of WT domination" (weaknesses–threats)—the defensive strategy, defined as mini–mini, corresponds to very high risk. This is a situation in which the project has a low design potential and is additionally characterized by a great number of threats usually related to the economic viability of the project. This most likely results from a low scale of innovation of the prototype being evaluated; probably in the future, such an innovation would be of high importance only for the implementing company and not the entire economy. Action in an adverse environment and the external threats are strengthened by the internal weaknesses of the project, contributing to the fact that the performance of such a project should be deeply considered in the context of changes of the design, operating assumptions, etc.

An invariable element will be the identification of the risk factors within the four basic SWOT/TOWS analysis areas. In addition, specific factors will be treated as the assessment criteria, and weights will be assigned to them.

3.2. The Proposed Model

The risk assessment process was divided into six stages.

In the first stage, the team of experts determines the assessment criteria, namely the risk factors related to the four analysis areas, such as strengths and weaknesses, as well as opportunities and threats.

In the second stage, the personality traits of the particular experts participating in building the prototype should be determined. Based on the analysis of the inventor's personality questionnaire, the personality traits were determined that can be used to describe the particular experts in the scope of such elements as [69–75]:

- Way of placing decision makers' control;
- Motivation to act;
- Need for stimulation.

According to the research being conducted [24], the desired expert is a person with the internal placement of control with the need to be successful and avoid thrills and thus stimulate incentives. According to this assumption, the importance of the particular experts in the team was determined.

Then, each expert assessed the importance of the adopted assessment criteria. The indicated weights were subject to pairwise comparisons to obtain relative weights, namely regarding the importance of different risk factors from the given area. Then, one common weight was calculated for each of the criteria and finally subjected to normalization to ensure that the weights under a particular priority area add up to 1.

In the third stage, the team of experts provide answers to some basic questions related to the SWOT analysis [48,68]:

1. Will the identified strengths allow taking advantage of the upcoming opportunities?
2. Will the identified strengths allow the threats to be overcome?
3. Will the identified weaknesses prevent taking advantage of the upcoming opportunities?
4. Will the identified weaknesses strengthen the impact of the threats?

and to the TOWS analysis:

1. Will the opportunities enhance the strengths?
2. Will the threats weaken the strengths?
3. Will the opportunities allow the weaknesses to be overcome?
4. Will the threats enhance the weaknesses?

opportunities (O),—threats (T), (3)—strengths (S), (4)—weaknesses (W).

At this stage, tables of interactions are prepared. The template of the interaction table is shown in Table 1. Moreover, the lower part of Table 1 presents an example of the interaction between strengths (S) and opportunities (O).

Table 1 should be completed following the principle: if a dependence occurs, enter "1"; if not, enter "0". The number of interactions signifies the sum of dependencies present. The product of weights and interactions signifies the multiplied value of weight values and the number of indicated interactions.

In the fourth stage, the innovation risk assessment for the prototype should be done. The results obtained from the cross boards should be collectively presented in the domination map (Table 2). The determination of the first point on the risk map, corresponding to O–T relations, is made by subtracting the number of interactions related to the threats from the number of interactions responsible for the project opportunities.

The determination of the second point on the risk map, corresponding to the S–W relationships, is made by subtracting the number of interactions related to the weaknesses from the number of interactions responsible for the project strengths. The results are presented so that they simultaneously reflect the assessment of the project on the map of the state of prototype domination. The highest number of interactions and the weighed number of interactions indicate the strategy which should be chosen for the prototype being analyzed.

On the other hand, the determination of the location of the point representing the prototype risk mathematically comes down to comparing the interactions that were determined in the SWOT and TOWS analysis as part of the O and T as well as S and W relationships.

Table 1. The template of the interaction table.

Relationship between Chosen Elements of SWOT/TOWS Analysis	General Assessment Criteria (CG)	Chosen Elements 1	…	Chosen Elements n	Weight W_{ij}	Number of Interactions	Product of Weights and Interactions	Importance
General assessment criteria								
Chosen elements 1								
…								
Chosen elements n								
Number of interactions								
Weight W_{ij}								
Product of weights and interactions								
Importance								
Total interactions **Total products**								

S/O	CG1	CG2	CG3	O1	O2	O3	O4	O5	O6
CG1				1	1	1	1	1	1
CG2				1	0	0	1	1	1
CG3				1	0	1	1	1	1
S1	1	1	1	1	1	1	0	1	0
S2	0	0	0	1	1	1	1	1	1
S3	1	1	1	1	1	1	1	1	1
S4	1	1	1	1	1	1	1	1	1
S5	0	1	0	1	1	1	1	1	1
S6	0	1	0	1	1	1	1	1	1

Details of example are presented in the next part of the paper in Table 3.

Table 2. Domination map.

<table>
<tr><td colspan="3" rowspan="4"></td><td colspan="2">EXTERNAL FACTORS</td></tr>
<tr><td>Opportunities</td><td>Threats</td></tr>
<tr><td>Maxi–Maxi</td><td>Maxi–Mini</td></tr>
<tr><td>Aggressive Strategy</td><td>Conservative Strategy</td></tr>
<tr><td rowspan="6">INTERNAL FACTORS</td><td rowspan="2">Strengths</td><td>number of interactions</td><td></td><td></td></tr>
<tr><td>weighed number of interactions</td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="2"></td><td>Mini–Maxi</td><td>Mini–Mini</td></tr>
<tr><td>Competitive Strategy</td><td>Defensive Strategy</td></tr>
<tr><td rowspan="2">Weaknesses</td><td>number of interactions</td><td></td><td></td></tr>
<tr><td>weighed number of interactions</td><td></td><td></td></tr>
</table>

In general, the determination of the location of the point that represents the prototype risk assessment involves the principle that smaller values are deducted from greater ones, and the so-defined differences are put aside on the particular axis on the side of the greater of the numbers.

The point of crossing the perpendicular lines to the axis going through these points determines the prototype risk assessment.

In the fifth stage, the intervals should be characterized for the possible effects that are related to the particular risk factors and the probability values of their occurrence. For this purpose, two categories should be prepared for the description of the effects of the strengths and the opportunities as well as the weaknesses and the threats. This modification was necessary, due to the application of the SWOT/TOWS method not only for the identification of the threats but also for the risk assessment, which, in the classical perspective, involves a determination of the product of the effect and the probability for each potential threat. In the conducted calculations, the equivalent of the probability parameter is the identification of dependencies between different factors. Here, due to the prototype assessment, the procedure was simplified to determine a 100% chance of occurrence (namely, the assignment of value 1 in the interaction field) or a 0% chance of occurrence (namely, the assignment of value 0 in the interaction field). Such a simplification seems to be acceptable due to the structural nature of the prototype being evaluated. Such a simplification also results in removing the given factor detectability value from the product that is proposed in the case of innovation assessment.

In the sixth stage, a report about the particular threats related to the prototype should be created. The risk assessment procedure with the use of the SWOT/TOWS analysis model is presented in Figure 1.

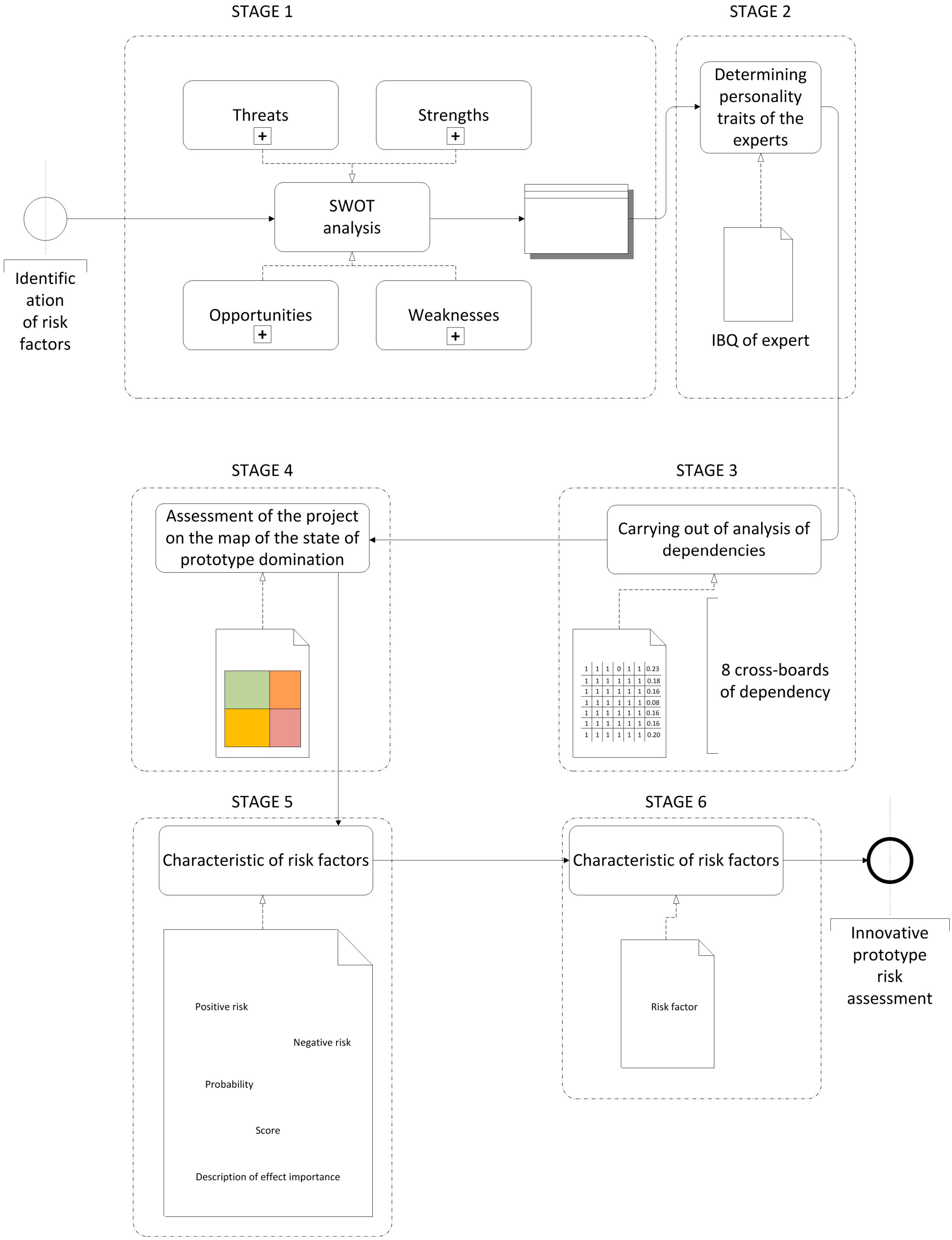

Figure 1. Innovation prototype of risk assessment method.

4. Innovative Hydraulic Cylinder Prototype Risk Assessment

4.1. Research Object

The object for which the risk assessment was carried out is a composite hydraulic cylinder. The project is being developed at a leading technical university in Poland. The team developing the object has many years of experience in working with composite materials as well as in the design of hydraulic drive components. They also have the technological know-how and machinery necessary to produce and test the prototype.

Hydraulic cylinders are a widespread group of hydrostatic drive components whose task is to convert the energy of fluid pressure into the energy of linear motion. Traditionally, these components are made of metallic materials (steel and aluminum alloys) with consequences such as high mass and susceptibility to corrosion and magnetic fields. To minimize these disadvantages, the designers decided to use composite materials and plastics, replacing metal elements with them.

4.2. Descriptive Characteristics of the Prototype

The strengths (S) are:

i. Mass effectiveness—reduced cylinder weight: The structure is made of lightweight materials (light-weighting): the hydraulic cylinder made of composite material is characterized by low mass, better resistance to atmospheric conditions and the effect of the electromagnetic field, with maintained required working parameters. As compared to the existing, traditional solutions, the application of the composite material allows for a 65% reduction in the cylinder weight, being of particular importance for the aviation, car, mobile machinery and construction industries. The base and head made from plastic allow for a further reduction in the actuator's mass. Simultaneously, the solution combines some elements of material engineering as well as mechanical engineering (in particular design and operation of machines with hydrostatic drive);
ii. Wide application in the following sectors—aviation, automotive, construction and maritime. On the other hand, high-pressure hydraulic system manufacturers are defined as the target group being the direct recipient of the technology. The analysis of the markets of actuators, high-pressure hydraulic devices as well as composite materials confirmed a good economic situation as well as an upward trend in these markets;
iii. Higher resistance to atmospheric factors with maintained desired working parameters—the making of a liner by rotary spraying or dipping technology allows a liner to be obtained from thermally and chemically hardened materials (also with fillers) with fixed thickness and surface quality. The elimination of the steel/aluminum liner makes it possible to minimize the differences in rigidity and thermal expansion coefficients between the element's layers (particularly critical at cyclical loads and temperature changes);
iv. Higher resistance to the effect of electromagnetic fields is obtained by eliminating or minimizing the presence of ferromagnetic materials;
v. The possibility to operate in increased temperatures (50–80 °C) is obtained by the selection of composite materials characterized by a high glass transition temperature. This allows the application of these materials in operation conditions in temperatures up to 80 °C. Such temperature values of the working liquid are more and more commonly found in machines and devices with a hydrostatic drive. This particularly applies to machinery working in underground conditions (e.g., LGOM mines);
vi. The possibility to obtain high working pressures at high efficiency—through the application of state-of-the-art composite materials, resistance to the effect of temperature and a liner made by the rotational spraying or dipping method allows high working pressures to be obtained (more than 20 MPa) with maintained internal and external tightness of the cylinder (volumetric efficiency) and not increased hydraulic losses on flow and friction in the cylinder (hydraulic-mechanical efficiency).

The threats "T" are:

i. Level of implementation readiness TRL—The TRL level (Technology Readiness Level) is used to determine the technological readiness of the particular solution on a nine-degree scale. Technological readiness is nothing else but the stage of development of a project from the broadly understood technology industry. The cylinder prototype was tested in an environment close to the natural one. Everything indicates that the end product can be created and will perform its tasks. Initial actions were conducted to confirm project feasibility, and, consequently, at the present moment, the implementation readiness level is 6;
ii. Failure to achieve the assumed design and operating conditions, including a reduction in mass, at the same time ensuring the cylinder's working parameters and bad selection of composite/nanocomposite materials;
iii. Accessibility of competitive solutions—cylinders made of composite materials are already available on the market (Parker product series—Lightraulics® products, Imenco Bauer products, Tenderlift Yacht Hydraulic System®—cylinders of the American company Polygon—PolySlide®);
iv. The need to conduct a repeated analysis of the violation of third-party intellectual property rights (the invention was internally reported in the university in the concept phase);
v. Restricted technological capabilities of machinery—directly affect no possibility to make improvements in and modify the cylinder.

The opportunities "O" are:

i. Only one serious competitor on the market—despite the existing competitive solutions on the market, it should be stated that only Lightraulic® products are characterized by a reduction in mass up to 60%, allowing the innovative cylinder prototype to eliminate the "weaker competitor";
ii. Extended sales possibility—in the future, there will be a possibility to sell not only the innovative product, being the hydraulic cylinder, but also the applied technology;
iii. Well-identified demand for cylinders on the domestic and foreign markets—(11 potential domestic recipients and 8 potential foreign recipients) hydraulic cylinders are characterized by a high potential for modifications;
iv. A growing interest in smart technologies in production—cylinders are one of the elements used in creating smart machines and equipment;
v. A further possibility to develop the cylinder—with the possibility to monitor the hydraulic devices' resources in real-time and forecast and detect defects in the smart wireless technology, it will be possible to make further improvements in the cylinder elements not listed in item 6;
vi. A further possibility to develop the composite piston rod, piston and base—(e.g., by pultrusion or pullwinding) could possibly lead to the development of a new actuator application within particularly aggressive environments, e.g., chemical or maritime industry, offshore.

The weaknesses "W" are:

i. Market pressure related to the development of composite cylinders—the market needs results in the fact that the production of innovative cylinders is still in the area of interest among potential suppliers of this product, which increases the number of potential competitors on the market;
ii. Widespread use of composite materials—the application of composite materials in the structure of the particular elements or entire cylinders has already been applied by several companies to manufacture hydraulic cylinders intended for the maritime, manufacturing and aviation industries;
iii. High production costs of carbon fiber—presently the efforts of companies and research centers focus on the optimization of carbon fiber manufacturing processes (reducing the costs of manufacturing and energy during the production process). A serious

competitor is composite hybrid materials combining carbon and glass fiber because they are less expensive;

iv. The long time for research and development as well as the production of carbon fiber may result in some problems concerning selecting the best material for the production of the cylinder;

v. The high defectiveness coefficient of carbon fibers used for the production of the cylinder contributes to the risk of the prototype being defective.

4.3. Application of the Innovation Behavior Questionnaire (IBQ)

In the second stage, the personality traits of the particular experts were determined. In this aim, we used the Innovator Behavior Questionnaire (IBQ) [63]. The IBQ includes 54 statements, which are presented in detail in [63]. The statements describe the practically observable behaviors of innovators. The correct selection of a team of experts forms a key factor in the success of implementing innovations in a company. At the design stage of the prototype, experts cannot be selected. However, it is possible to assign weights to designers according to more or less desirable features. For this purpose, the IBQ was used.

4.4. Dependencies Occurring between Strengths and Opportunities

In the third stage, the team of experts gave answers to some basic questions related to the SWOT and TOWS analysis. At this stage, eight cross boards were prepared for each of the adopted assessment criteria (examples of the analysis of dependencies occurring between strengths (S1, . . . , S6) and opportunities (O1, . . . , O6) are presented in Table 3).

Table 3. Dependencies occurring between strengths and opportunities.

S/O	CG1	CG2	CG3	O1	O2	O3	O4	O5	O6	Weight	Number of Interactions	Product of Weights and Interactions	Importance
CG1				1	1	1	1	1	1		6		
CG2				1	0	0	1	1	1		4		
CG3				1	0	1	1	1	1		5		
S1	1	1	1	1	1	1	0	1	0	0.23	7	1.58	1
S2	0	0	0	1	1	1	1	1	1	0.18	7	1.23	4
S3	1	1	1	1	1	1	1	1	1	0.16	9	1.46	2
S4	1	1	1	1	1	1	1	1	1	0.08	9	0.71	6
S5	0	1	0	1	1	1	1	1	1	0.16	7	1.09	5
S6	0	1	0	1	1	1	1	1	1	0.20	7	1.43	3
Number of interactions	3	5	3	9	7	8	8	9	8				
Product of weights and interactions				1.80	0.82	1.07	1.89	1.54	1.14				
Importance				2	6	5	1	3	4				
Total interactions total products	**121** **15.73**												

Table 3 was created through the identification of dependencies between different factors following the principle: if a dependence occurs, enter “1”; if not, “0”.

In column and row “weight”, earlier determined weights were entered for each criterion, which is simultaneously a risk factor. Each expert determined the importance of the evaluation criteria adopted (Formula (1)). The criteria that are defined as general criteria are an exception. General criteria were not treated in the subsequent stages of the analysis as risk factors; therefore, weights were not assigned to them. However, they were introduced to the table due to their significance in further innovation risk assessment. They have an effect on the determination of the number of interactions between the particular risk factors. The indicated weights were subjected to a pairwise comparison procedure [24] in order to obtain weights of a relative nature, i.e., with respect to the importance of individual risk factors from a given area.

The method of comparing pairs according to the following Equation (1) was used in the elaboration of the weight of criteria:

$$w_j = \sum u_{ji} \quad j, i = 1, \ldots, m \tag{1}$$

where:

w_j—the weight of criterion of chosen elements of area: "S", "W", "O", "T";

u_{ji}—assessment of the weight of a given pair of chosen elements;

u_j,u_i—elements of the area: "S", "W", "O", "T".

If the u_1 element is more important than the u_2 element, then values from the range $0.5 < u_{12} \leq 1.0$ are entered in the row u_1 under u_2, whilst the value $u_{21} = 1 - u_{12}$ is entered in the row u_2 under u_1. In an equivalent case, the value $u_{15} = u_{51} = 0.5$ is entered. Zeros occur on the matrix diagonal as a criterion cannot be weighed against itself. Then, the obtained weights are subject to normalization [24]. The pairwise comparison procedure makes it possible to objectify the study by specifying relative weights.

The importance determines the power of the risk factor. The names of the criteria were specified according to the abbreviation, which corresponds to the item number in the description of the particular criteria. For example, S1 is the first of the aforementioned prototype strengths, namely mass effectiveness, and CG1 is a general criterion—a scale of the innovation prototype.

4.5. Domination Map

In the fourth stage, the innovation risk was assessed for the hydraulic cylinder prototype. The results obtained from the cross boards are collectively presented in Table 4. The results are presented so that they simultaneously reflect the assessment of the project prototype domination map.

Table 4. Domination map.

			EXTERNAL FACTORS	
			Opportunities	**Threats**
			Maxi–Maxi	**Maxi–Mini**
			Aggressive Strategy	**Conservative Strategy**
INTERNAL FACTORS	**Strengths**	number of interactions	121	100
		weighed number of interactions	15.73	13.04
			Mini–Maxi	**Mini–Mini**
			Competitive Strategy	**Defensive Strategy**
	Weaknesses	number of interactions	113	96.00
		weighed number of interactions	16.02	13.58

The dominance map is equivalent to the risk map used in project risk assessment. After introducing the appropriate modifications described in the article (resulting from the assumptions of the SWOT–TOWS analysis), it can be interpreted as a classic risk map.

The dominance map is a convenient tool for presenting the partial risks of a given project in a graphical form. The map shows the relationship between chosen elements SWOT–TOWS analysis.

The map contains color-coded fields as follow the particular risk levels (low—green, medium—yellow, high—orange, very high—red). The purpose of interpreting the map is always to identify risks from high- and very high-risk areas. Then, one can identify actions that could cause them to move toward a low- or medium-risk area. The remaining risks should be monitored and controlled.

The determination of the first point on the domination map, corresponding to O–T relations, is made by subtracting the number of interactions related to the threats (206) from the number of interactions responsible for the project opportunities (226), which gives a result of 20, and this is put aside on the side of the opportunities.

When determining the O–T relationship, intermediate calculations are used, resulting from the records made in the cross tables:

1. The number of interactions that correspond to O (226) and are a result of the answers given to the following questions:
    - Will the opportunities enhance the strengths?—number of interactions from the TOWS analysis = 126;
    - Will the opportunities allow the weaknesses to be overcome?—number of interactions from the TOWS analysis = 100.
2. The number of interactions that correspond to T (206) is a result of the answers given to the following questions:
    - Will the threats weaken the strengths?—number of interactions from the TOWS analysis = 122;
    - Will the threats enhance the weaknesses?—number of interactions from the TOWS analysis = 84.

The determination of the second point on the domination map, corresponding to the S–W relationships, is made by subtracting the number of interactions related to the weaknesses (209) from the number of interactions responsible for the project strengths (221), which gives a result of 12, and this is put aside on the side of the project strengths.

When determining the S–W relationship, intermediate calculations are used, resulting from the records made in the cross tables:

1. The number of interactions that correspond to S (221) and are a result of the answers given to the following questions:
    - Will the identified strengths allow for taking advantage of the upcoming opportunities?—number of interactions from the SWOT analysis = 121;
    - Will the identified strengths allow for the threats to be overcome?—number of interactions from the SWOT analysis = 100.
2. The number of interactions that correspond to W (209) and are a result of the answers given to the following questions:
    - Will the identified weaknesses prevent taking advantage of the upcoming opportunities?—number of interactions from the SWOT analysis = 113;
    - Will the identified weaknesses strengthen the strength of the impact of the threats?—number of interactions from the SWOT analysis = 96.

The point with coordinates 12 (S) and 20 (O) graphically represents the prototype risk and is presented on the risk map (Figure 2).

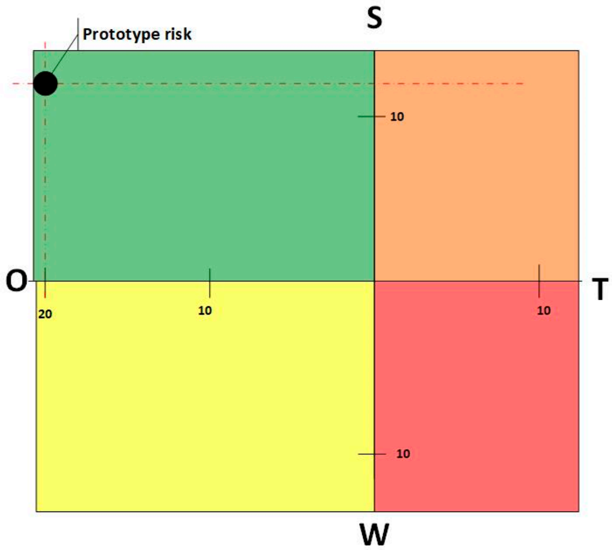

Figure 2. Prototype risk map.

4.6. Characteristics of Risk Factors

In the fifth stage, the intervals were characterized for the possible effects that are related to the particular risk factors and the probability values of their occurrence. For this purpose, two categories were prepared for the description of the effects of the strengths and the opportunities as well as the weaknesses and the threats (Table 5). The descriptions were prepared by a team of experts.

Table 5. Scores for the effect and the probability of different risk factors.

Positive Risk—Strengths and Opportunities Area		**Probability**	**Negative Risk—Weaknesses and Threats Area**	
Score	Description of effect importance	Interval	Score	Description of effect importance
1	Additional improvement of the design parameters having smaller importance for the cylinder's efficiency	0–40	1	Deterioration of the design parameters having smaller importance for the cylinder's efficiency
2	Smaller costs than assumed	41–50	2	Higher costs than assumed
3	Greater cylinder weight reduction than assumed	51–70	3	Smaller cylinder weight reduction than assumed
4	Smaller costs than assumed, and at the same time, greater cylinder weight reduction than assumed	71–80	4	Higher costs than assumed, and at the same time, smaller cylinder weight reduction than assumed
5	Smaller costs than assumed and greater cylinder weight reduction than assumed, with the simultaneous improvement in selected design parameters	81–100	5	Higher costs than assumed and smaller cylinder weight reduction than assumed, with the simultaneous deterioration of selected design parameters

4.7. Development of the Report

In the sixth stage, a report about the particular threats related to the prototype was created. The intervals of the scores describing the effect of the occurrence of the given threat and its probability of occurrence were used for this purpose and are presented in Table 5. The starting point to determine the probability of the different risk factors was the number of interactions that occur within the SWOT/TOWS analysis; dividing them by the maximum possible number of the interactions that could have arisen (namely 17), then, the obtained values were compared with the intervals recorded in Table 6. The table was developed by a team of specialists, and the colors used in it correspond to the particular risk levels (low—green, medium—yellow, high—orange, very high—red).

Table 6. Statement of results for particular threats.

P	S	Risk	Risk Factor
5	5	25	Competition in the cylinders market
4	5	20	Mass effectiveness
4	5	20	Widespread use of composite materials
4	5	20	Failure to achieve the assumed design and operating conditions
4	4	16	Higher resistance to atmospheric factors
4	4	16	High production costs of carbon fiber
4	4	16	A long time for research and development as well as the production of carbon fiber
4	4	16	High defectiveness coefficient of carbon fibers
4	4	16	Only one serious competitor on the market
3	5	15	Wide application
5	3	15	Implementation readiness level TRL
5	3	15	Accessibility of competitive solutions
4	3	12	Possibility to obtain high working pressures at high efficiency
3	4	12	Extended sales possibility
4	3	12	A growing interest in smart technologies in the production
4	3	12	A further possibility to develop the cylinder
4	3	12	Possibility to modify the composite plunger rod, plunger and heads
4	3	12	Restricted technological capabilities of the machinery
3	3	9	Well-identified demand
4	2	8	Need to conduct repeated analysis of the violation of third-party intellectual property rights
4	1	4	Higher resistance to the effect of electromagnetic fields
4	1	4	Possibility to operate in increased temperatures

5. Results and Discussion

The conducted assessment of the innovative hydraulic cylinder prototype indicated that it is justified in continuing works related to the commercialization of the prototype.

In the applied six-stage assessment procedure, the state of prototype domination was determined as an SO configuration (strengths and opportunities), which is an argument for taking actions typical of the aggressive strategy. The prototype risk was determined as low, and therefore, it is certainly justified to introduce the proposed solution to manufacturing.

It is also worth paying attention to a slightly more cautious approach of the experts to the assessment concerning the result obtained based on the number of interactions. According to the research procedure, weights that the experts assigned to the particular risk factors should also be considered. An expression of this is the weighted number of interactions. According to the values indicated on the map of domination, taking into account the experts' weights, the state of prototype domination should be identified as a WO combination (weighted value of interactions 16.02). However, it should be emphasized that this result does not vary significantly from the one obtained in the SO combination (15.73), which confirms low prototype risk to some extent. The WO combination implies the competitive strategy, which also involves the advantage of the opportunities over the threats; however, with the domination of project weaknesses. Therefore, it is worth paying special attention to the assessment of the different risk factors which, according to the independent calculation procedure resulting from preparing the risk report, are included in the risk report.

According to the prepared statement (Table 4), particular attention should be attached to all actions that may have an impact on:

1. The emergence of new competitors and new solutions regarding hydraulic cylinders (competition on the cylinders market);
2. Change in mass productivity;
3. The emergence of new composite materials (widespread use of composite materials);
4. Failure to achieve the assumed design and operating conditions.

Within the report, the average risk area also included:

1. Higher resistance to atmospheric factors;
2. High production costs of carbon fiber;
3. A long time for research and development as well as production of carbon fiber;
4. High defectiveness coefficient of carbon fibers;
5. Only one serious competitor on the market;
6. Wide application;
7. Implementation readiness level TRL;
8. Accessibility of competitive solutions.

Therefore, it is also worth bearing these factors in mind, as their assessment in adverse conditions could very easily be moved to the high-risk area. It can also be noticed that the expected increased application of composite materials in the machine construction industry may lead to cost reductions and reduced defectiveness of composite fibers.

6. Conclusions

The assessment procedure presented in the paper dedicated to innovative prototypes has its own universal application and, after taking account of individual risk factors, can be successfully used on a larger scale.

The main goal of hazard identification in any investment project is to avoid project failure. However, it should be borne in mind that, in addition to avoiding project failure, hazard identification can have a significant impact on improving the quality and functionality of the prototype. The designer should keep in mind not only the improving efficiencies but also the benefits of improving the technical performance of the project. Risk assessment requires the dedication of additional time by a team of experts but is also an opportunity to improve the performance of the prototype. Conducting it, therefore, may have unassessed benefits that cannot be converted into the amount of time required to conduct it.

Its undoubted asset is a consideration for the team of experts that has been characterized in terms of the propensity to take risky actions.

It should also be emphasized that the applied solutions based on the SWOT/TOWS analysis open a wide field for interpretation, not only concerning comprehensiveness but also individual assessment in the areas of the different risk factors.

Like any method, the proposed approach is not without flaws. The main limitation of the proposed approach is related to the impossibility of eliminating 100% subjectivity in the evaluation of experts. A major complication is also the necessity of combining knowledge of interdisciplinary character in this type of project. Clearly, the designer–technologist is not able to analyze the economic issues of the project and vice versa. The formation of an interdisciplinary team is therefore a necessity. The lack of data in the field of prototype testing makes experts determine the selected probabilities subjectively. Additionally, this is where the problem of objectifying individual approaches arises. The use of the IBQ questionnaire and the conversion of the given weights by the pairwise comparison method partially eliminates this problem, as does the issue of overestimation and overestimation of the evaluation parameters, but it is not guaranteed to eliminate it completely.

The element that can be classified as a certain limitation of the method is a relatively high number of calculations involved in the conduct of the applied method. However, there are undoubtedly many advantages resulting from the use of the method. These include:

- The development of a specific procedure of conduct that applies to prototypes and not just innovation;
- The application of the neutral concept in risk estimation;
- Reduced subjectivity in the assessment by the application of a team of experts with specific psychological traits, the identification of which is to eliminate extremely risky assessments, being a new contribution to the use of the SWOT/TOWS analysis;
- The possibility to visualize the results on risk (domination) maps;
- A combination under one assessment procedure of two independent approaches to risk estimation (one related to the preparation of the map of domination results from the assumptions of the SWOT/TOWS analysis, the other associated with the preparation of the risk report);
- Freedom in updating the assessment result at every stage of the project implementation.

In addition, the procedure is open and, in the future, it will be possible to expand and modify it to connect the assessment directly with the commercial dimension of the prototype.

Author Contributions: Conceptualization, A.M.D., M.L. and M.S.; methodology, A.M.D. and A.D. (Adam Deptuła); software, A.D. (Adam Deptuła) and M.K.; validation, A.M.D., M.K. and K.U.; formal analysis, A.D. (Adam Deptuła), M.L., M.S., M.K., P.S. and A.M.D.; investigation, A.D. (Adam Deptuła), M.S., M.K., M.L. and A.M.D.; resources, M.K. and A.D. (Adam Deptuła); data curation, A.D. (Adam Deptuła), K.U., M.S., M.K., K.U. and P.S.; writing—original draft preparation, A.D. (Adam Deptuła), A.D. (Algimantas Danilevičius), M.S., M.K., K.U. and P.S.; writing—review and editing, A.M.D., M.S., M.K., K.U. and M.L.; visualization, A.D. (Adam Deptuła), P.S., M.S., M.K. and A.D. (Algimantas Danilevičius); supervision, A.D. (Algimantas Danilevičius), A.M.D. and M.K.; project administration, P.S.; funding acquisition, A.D. (Adam Deptuła), M.S., M.K. and A.M.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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