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Product Development Anxiety: A Contingency Planning Model for Innovative Production Companies

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Abstract: This paper investigates the possible failure modes of the product development process in production companies that are active in the B2C markets with a focus on household products. Since these cases require short lead times and are difficult to differentiate, in many instances the result will not be the desired one and could affect profitability for a season or for good. A model of these possibilities is created and an approach to plan contingencies for their solutions is proposed in the article. The main guideline is to switch from failure probability determination to accepting failure as inevitable and using digital solutions to reinforce the development process to offset its impact. For this goal, an Industry 5.0 Abatement Factor (abbreviated IFAF) is introduced in the contingency planning approach, which factors in the evaluation of the low cost of digital instruments and the proper mix of Technology, Humans, and AI (abbreviated THAI). The new working procedure based on these concepts and their interlinkages is discussed based on specific examples.

Keywords: new product development; contingency planning; Industry 5.0; artificial intelligence

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1. Introduction

The manufacturing industry is as important to a country's economy as it is sensitive and complex to change. Production systems have grown more intricate in the past few decades and the resources invested in their operations are significant, in most cases. Although the delocalization and offshoring trend is still present, many countries are investing considerable effort in developing advanced production capabilities that are adapted to the challenges of the present, from resilience to sustainability. The new product development (NPD) process is a key component of this industrial landscape, as it compounds the technological side with the human-centered perspective, in which creativity is called upon to develop ever-new and ever-successful solutions to keep the companies competitive in the market.

As pressures intensify, the talk of failure becomes taboo, and the risk management process is seen as a panacea for solving any situation. However, despite the best practices and the best people, NPD sometimes fails and sends the production company into deep anxiety about its future survival. In the current paper, the authors propose and test a different approach to managing risks in this process, not by trying to avoid them but rather embracing them as an inevitable part of a firm's life and developing contingency mechanisms to handle them "online" as soon they are manifested, making use of the best new technologies and human resources approaches.

By changing the paradigm, it is possible to make valuable use of hidden creativity mechanisms and facilitate the achievement of more significant and disruptive innovations. Even if the current technologies are not sufficient to mitigate all dangers, in the long run, it is possible to uncover a large value-added potential that will remarkably change the return on investment associated with NPD. The framework proposed in this article makes use of AI instruments at its core, but it is similarly rooted in aspects related to failure management and production system resilience, thus enabling a robust method for overcoming the above-mentioned anxiety and finding valuable solutions that can translate into products that are able to reach higher maturity levels in the design phase and, consequently, are more successful on the market.

The conceptual development is based on the existing literature and over 20 years of experience in the field of production engineering, while the model proposed is founded on a conceptual framework and detailed through an application procedure. Also, the validation of the development is realized using interviews and industrial cases from the innovation and entrepreneurship ecosystem that the authors collaborate with. The discussion included in the paper touches on the advantages and disadvantages of using such an approach and makes a future projection about the possibilities to further evolve the methodology as technical capabilities become more advanced and access to them becomes cheaper and easier.

2. Materials and Methods

The current study is based on a straightforward but robust research methodology that makes use of the current state of the art, as well as the industrial experience of the authors and their working ecosystem for product development and manufacturing (see Figure 1 below).

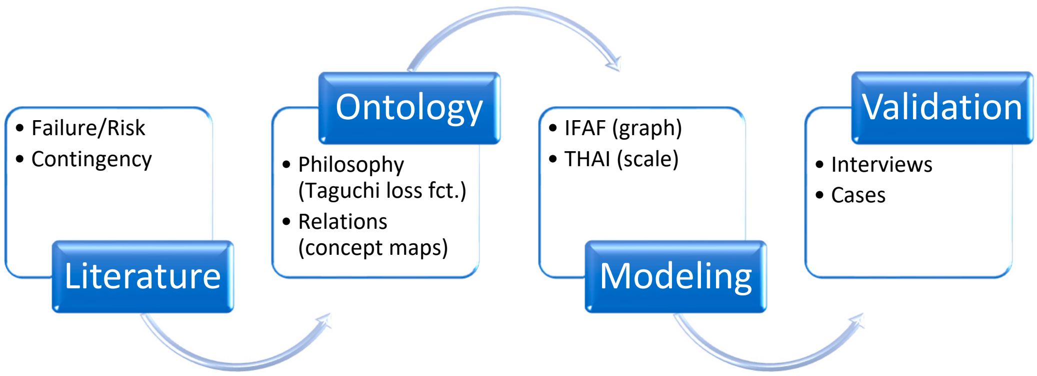

Figure 1. Research methodology for studying NPD failures and developing improved contingency plans.

In the first step of the undertaking, a thorough literature review has been performed using as a frame of reference the past 5 years (2020–2024), a MEAL plan, which consists of the following tasks for each conceptual area, Main idea—Evidence—Analysis—Link, has been applied Three main scientific databases have been used, namely, Science Direct, Google Scholar, and Web of Science, to collect and analyze 37 research papers responding to the keywords "product development failure", "product development risk", and "product development contingency". They have been ascribed to the area of generic industrial and household products that can be manufactured by production facilities (excluding complex—like medical devices—or specific products—like foodstuffs). The second step of the methodology has been dedicated to creating an adequate basic ontology to address the identified and encountered issues in identifying, treating, and avoiding unwanted outcomes of the product development process. The basic philosophy proposed by the authors stems from the concept of loss function proposed by Genichi Taguchi, which inverts the positive impact into a minimally detrimental outcome. As Taguchi considers quality to be "minimal loss to society", in this case, the authors consider successful NPD as the minimal number of failures possible, thus considering that current technological instruments such as CAE, AI, and robotics are developed enough to treat any and all risks, without the need for complex identification, categorization, and assessment procedures. Also, in this phase, concept maps are used to establish the main connections and relationships between associated topics, which are used in the next phase to model NPD risks. In the third step, the authors propose the introduction of two related notions based on brainstorming and interviews with industry representatives. The first one is called the Industry 5.0 Abatement Factor (IFAF) and complements the two-dimensional risk analysis in terms of severity and probability with the capability of Industry 5.0-related technologies to solve any issues, thus turning the assessment space into a three-dimensional one where recognition is more important than evaluation and most, if not all, risks can be mitigated on the go. Should any risks persist, it would be advisable to address them through alternative instruments outside of the production system (e.g., change management, organizational culture, insurance, etc.). Furthermore, to define the IFAF, a new classification of available tools is introduced, and a proper scale of understanding is proposed using the THAI acronym: Technology, Humans, and Artificial Intelligence. Finally, the theoretically proposed approach is validated using a series of interviews and case studies from various industries, which are summed up in the concluding chapter of the paper. A discussion of the strengths and weaknesses of the framework is included and elements to further develop this study in the future are proposed.

3. Results

3.1. Literature Review

Thoroughly analyzing the fields of NPD and contingency planning is a complex endeavor, whose results are presented below to gauge the context in which the research work was conducted. Contingency is a complex concept, with philosophical ramifications [1], and a myriad of possible complex implementations and applications [2] from business development to emergency management and cybersecurity. Its accomplishment in manufacturing and, especially, the NPD process draws on contributions from psychology, engineering, and quality management, thus making it a complex endeavor that is well suited for the use of advanced technologies included in the Industry 5.0 concept. As mentioned by one of the consulted studies [3], NPD is a structured and coherent form in which the entrepreneurial orientation of the company (its owners and employees) is manifested through the adequate business model, thus underlying the need to think about success and failure in a flexible manner, which could interconnect human intuition and machine reasoning. It can range in its target from concrete physical products (either industrial or for consumers) to more nuanced interface and interaction design [4] and can even create entire virtual worlds, such is the case for the gaming industry.

The results of the PDMA 2021 global survey [5] show that the best performance in NPD is achieved by companies oriented towards new markets and new technologies, which have a mature long-term risk culture and are willing to invest considerably in this process. Based on a sample of 436 manufacturing companies in Canada, the study by [6] reinforces the importance of learning valuable lessons after the often-encountered and mostly difficult failure of innovation projects. The authors underline the transformative power of failure and propose various interventions to strengthen and deploy it to its fullest extent through employee involvement, adequate risk culture, and conscious initiative-taking management. The literature shows an important link between contingency and learning from one's own mistakes, as underlined by [7], who finds that team dynamics and cohesiveness are the most important factor in fostering learning, while project complexity and various sources of disturbances and uncertainty have a negative effect. Under these conditions, the authors recommend a higher tolerance for ambiguity, doubled by adaptability within the organization. Another study [8], which surveyed 237 project managers who lead advanced NPD projects, reached the conclusion that simple learning from failure is not sufficient. Instead, the authors recommend developing the long-term experience of managers dealing with NPD failures, increasing their error management skills, and separating the failure moment and the learning phase by a considerable time.

The authors of [9] outline the role of product development failure in business strategy with application in the pharmaceutical industry, which is known for its complex and highly regulated product development. The study shows that companies experiencing failure are more likely to seek contingency solutions in the form of business alliances that have not been previously explored. The authors of [10] studied the impact of using big data in the South African mining industry using a sample of 520 questionnaire answers and identifying a strong relationship between supply chain performance and green product development. This is, however, contingent on increasing the skill levels of employees involved in this process, as is the case in the manufacturing sector, too. The ability to learn and integrate knowledge quickly in the organization is just as important as the ability to unlearn swiftly and thoroughly in order to foster new waves of innovation and increase its originality, as revealed in a study addressing responses from 242 Chinese firms [11].

While analyzing 249 Chinese companies, the authors of [12], while analyzing the use of big data analytics concerning the customers in the NPD process, have found that exploitative learning from customers must be balanced by high levels of market understanding to achieve the desired results, while also diminishing the impact of external technological changes. Also, in preparation for the successful use of customer analytics, the firms should be able to develop their own internal knowledge integration approaches.

For the past 50 years, the NPD field has been dominated by well-structured methodologies, with clear techniques to implement them and many examples of improvement methodologies applied to them [13]. However, in the article by [14], the researchers identify a number of limitations of approaches like Kansei Engineering, the Kano Model, Quality Function Deployment, and the Theory of Inventive Problem Solving related to subjectivity, rigidity, and low communicability, while the new, more unstructured AI-based tools bring larger requirements base to the process, an ability to work with dynamic data, and advanced representation capabilities. The authors of [15] review the possibilities of applying various AI approaches in design engineering endeavors and arrive at a complex landscape that requires guidelines and procedures for adequate selection of the tools. At the same time, the team publishing [16] identifies, based on the literature, applications of AI in multiple forms across all the stages of the product life cycle, from initial ideation to monitoring and improvement during use. These are key factors in considering the automation of risk management proposed in the current paper, as it indicates that at the moment the main downside is not the absence of the proper instruments but rather the difficulty in using them, either due to too many options or insufficient proficiency.

The article by [17] performs a complex analysis of 364 articles about the use of AI in corporate innovation, covering delicate topics, such as open innovation, market performance, and business models, defining a new comprehensive framework. In this perspective, AI becomes critical to maintaining the competitive advantage of companies, and an AI management structure is recommended to coordinate the internal process of its technological diffusion. Cooper [18] performs a meta-analysis of published research in the field of NPD using AI and concludes that there are considerable benefits related to this issue, from reducing time to market to enhancing product functionality and improving customer engagement. The article urges the immediate integration of AI technologies in the NPD process as a game-changing tool. However, a study conducted with 459 participants [19] showed that there is a significant human bias in evaluating the creative performances of AI systems, especially for products with low novelty and high usefulness and when the persons assigning scores perceived their jobs to be threatened by AI. This leaves open an important niche for AI to contribute to innovative products in ways that can command a market premium. Lee [20] explores a more subtle connection between using AI in NPD and social sustainability. The analysis the author performs encompasses 52 publications and concludes that there is a positive effect on the needs of society for using AI and big data in creating new products, and that the diversity of social impacts of product development is increasing over time.

According to [21], when using AI, it is possible to address in the product development and design stages a large number of variables (significantly more than when relying exclusively on humans) responding in a better way to the needs and requirements of the customers. The authors of the study point out that this will lead to products that are more human centered and can be manufactured in more human-centered processes. This seems paradoxical but comes to reinforce the idea that AI has the capability to augment human thinking for the benefit of other humans if properly employed. Other researchers [22] consider that ChatGPT alone has a good potential to support design innovation and related functions, such as training and education, and knowledge management, which may influence the output of an NPD process. They also identify its limitations in terms of accuracy, limited experience, and possible "AI hallucinations" determined by its prediction algorithms. Some authors [23] emphasize the strengths of both sides in creating hybrid innovation teams, which can deliver better results using established innovation frameworks. Their paper also discusses the more delicate issues of trust between humans and AI and the possible unforeseen outcomes of this collaboration.

In parallel with using AI as a tool, NPD processes are nowadays asked to deliver results in terms of sustainability and materials employed [24] and to answer the important threats to the natural environment. In the study by [25], the authors approach the topic of NPD for lowering the carbon footprint through a customized design for X methodology. Their conclusion is that by implementing the 30 design principles validated through the Delphi method by a panel of 14 experts, there is a high chance of reducing carbon emissions, demonstrating the flexibility of the NPD process in the face of new and complex challenges at the same time. In another work [26], the NPD process is conceptualized through the lens of the business strategy, which is a key component of achieving competitiveness from the start-up phase, and the recommendation of the authors also focuses considerably on sustainability, including advanced materials, enhanced recyclability, and smart features for the studied furniture products.

According to [27], ensuring that the success of NPD is encountered at the intersection of a multitude of internal and external factors, from organizational governance to team dynamics and technological trends. In this perspective, it makes sense that risks can be generated from a variety of causes, which can never be completely analyzed and even if they are, they will soon change; therefore, the risk management process is never complete.

In [28], 61 articles regarding risk management in product development are analyzed and connected within an overall understanding of the topic, which is of critical importance to the manufacturing sector. The findings describe the eclectic nature of the field, with many aspects to consider and a wide array of techniques to use, but at the same time, they are based on underlying and knowledgeable processes. The authors of [29] develop an interesting conclusion regarding the possibility of the NPD process ending in failure, which is actually the most common outcome, as they find that companies experiencing both success and misfires are more likely to terminate risky projects early. In our view, this is a consequence of the need to free up the time and creativity of people sooner for more auspicious projects rather than engage in endless review cycles.

Another aspect to consider, according to [30], is the shifting dynamics and perceptions of risk, which tend to vary with time and the organizational structure. As the authors of the study uncovered, as companies mature, there is a tendency to become more risk averse and switch to time-tested solutions or minimal-risk innovations, but this complacency can be dangerous in a very competitive marketplace. Introducing AI into the risk management process has the advantage of being immune to psychological factors, and the preparation for contingency situations can become more unbiased.

3.2. Ontology Development

The approach presented in this paper is based on a paradigm shift concerning the conceptualization and operationalization of the concept of risk in manufacturing enterprises. As detailed in Section 3.1 above, risk is approached as a probable negative event that might affect the expected course of events in the design and production phases of industrial and consumer goods. The authors propose that risk determination and classification, which usually follow risk identification, can be significantly simplified by adopting the philosophy of the Taguchi Loss Function [31], namely, in the product development phase, risk will be manifested no matter what approach to mitigate it is adopted; thus, the best course of action is to aim for a minimal amount of disruption. This relies on two complementary approaches: risk identification should be performed as detailed and extensively as possible and modern, AI-based, and, if possible, automated instruments to diminish them as they occur should be implemented in all situations. By adopting this line of thinking, considerable human resources can be freed, and their contribution can be oriented towards increased creativity, where AI is far less adequate to provide solutions. At the same time, other technological support instruments, like visualization and big data analytics, together with the intuition and knowledge of the involved personnel, can further contribute to the a priori limitation of diverse types of risks. This means that the occurrence probability will not constitute a concern anymore (as it will be 100% in all cases) but will be substituted with the capability of the mentioned tools to limit the severity of the impact for all risks.

A considerable amount of effort and anxiety in the NPD process is generated by the uncertainty associated with the occurrence of risks and their transformation from potential events into real problems that must be addressed. The main goal of changing the way in which risks are treated is to be able to redirect the capabilities used for managing this potentiality towards the actual work that must be performed by product developers and designers. Even if some risks are overlooked or improperly addressed by the technological components, which is to be expected in the beginning, the value added of freeing this time and creative energy could still offset the drawbacks.

An important aspect in creating a new risk ontology for the NPD process in production companies is to rethink the relationship between the main concepts involved in the risk management process, including hazards, occurrence probability, the severity of impact, the detectability of issues, mitigation measures, documentation, learning, and actualization, required skills, monitoring and decision making, follow-up actions, management instruments, technological tools, AI-powered tools, etc. A proposal for this modified network of relations is presented in Figure 2 below using the concept map approach implemented in yEd Graph editor software, version 3.23.2, using the Entity relationship graphic formalism. While elaborating this chart, the methodological base of the international risk management standard ISO 31000:2018 [32], as well as some well-known qualitative risk methods, like FMEA (Failure Modes and Effects Analysis) and FTA (Fault Tree Analysis), have been observed to maintain compatibility with the existing frameworks.

As can be noticed, the AI-powered tools will form the center of the novel approach, requiring zero human implications to transform the hazards into quasi-automated follow-up measures that remove the risk of failure in new product development. Moreover, this also removes the anxiety of failure and makes the human capabilities for innovation available, while technology is responsible for contingency planning. Figure 2 presents in a logical framework the three main components of the new approach (technological tools, AI-powered tools, and human managerial styles) as determinants of the new skill set needed to determine mitigation measures for hazards and monitor their implementation, which is a new understanding of the classical occurrence–severity–detectability triad, which is replaced by repeatability–mitigability–identity and effectiveness–limitation–overpass decisions, respectively. The figure is also color coded, with the newly introduced and enhanced components colored in red, the classical steps colored in blue, and the transformative components colored in green. Also, the follow-up stage is colored purple as it becomes a mix of the classic and modified elements in the new paradigm.

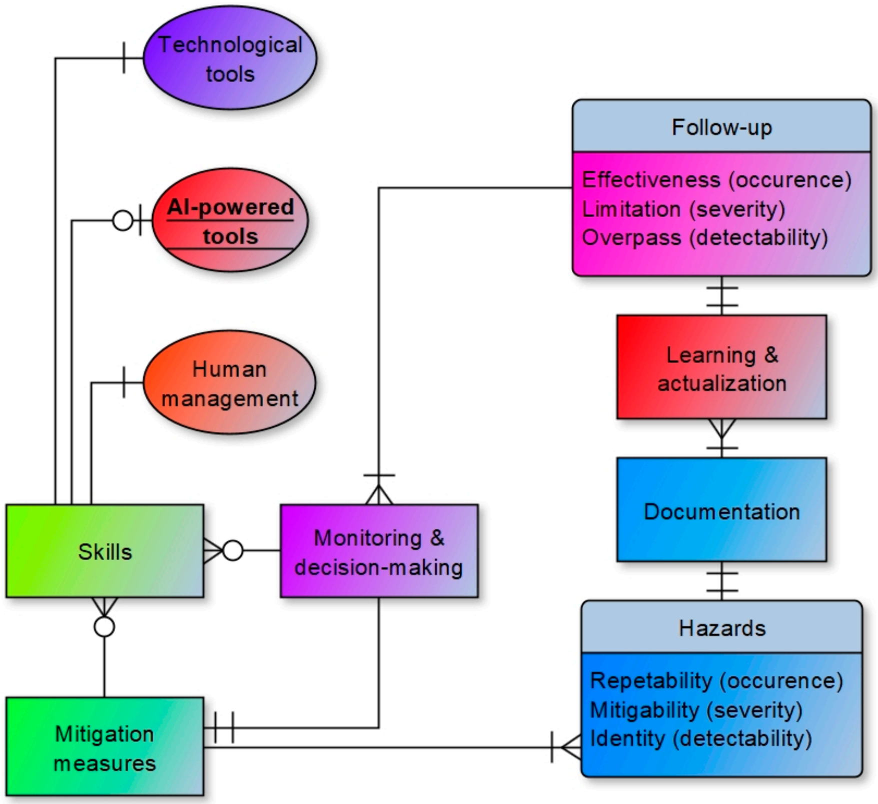

Figure 2. Concept map for the modified risk management approach.

3.3. Risk Process Modeling

In the following stage of investigation, the risk management process and its transformation according to the concept map has been modeled. For this to be achieved, the notions of the Industry 5.0 Abatement Factor (IFAF) and Technology, Humans, and AI instruments (THAIs) will be made explicit.

The IFAF represents the mathematical and graphical transformation of qualitative risk methods from the impact probability two-dimensional space to a three-dimensional space that can verify the capability of inline mitigated risk to be overlooked in the NPD phase. All technological instruments, human resource skills, and AI-powered tools that can be deployed without additional analysis or oversight are included in this concept that modifies the classical risk matrix, which has intervention zones made with colors ranging from green to black into a spatial representation, showcasing the limited and acceptable risks in the new approach [33]. The IFAF will have a value between 0 and 1, depending on the mix of measures that are used to remove and diminish the risks (if the value is 0, then the measures are completely successful, and if the value is 1, then the measures are ineffective).

In the following, an example of the utilization of the novel approach is provided. In Table 1, a classical situation in which a group of three risks is analyzed on the probability and severity dimensions, with their product and resulting intervention zone being calculated and assimilated to a usual form of recommended action based on "common knowledge" and standardized requirements.

Further on, in Table 2, the IFAF is introduced as a third factor in the product, modifying the intervention zone into "green" and thus acceptable risks in all exemplified cases. As the IFAF is between 0 and 1, it will reduce the impact of the overall score and will also modify the position in the risk visualization stage.

In Figure 3, the position of the three risks is plotted in the risk matrix that uses the two evaluation directions as a modeling space. Depending on the color of the risk zone, the recommended actions can be conceived to diminish or mitigate the risk, depending on the intervention being on the process/probability or the impact/severity scale.

Table 1. Classical risk approach in NPD with a two-dimensional assessment.

Risk Identification	Probability (Scale 1–5)	Severity (Scale 1–5)	Product (PxS)/Interv. Zone	Recommended Actions
Risk 1	3	5	15/Red	Emergency
Risk 2	2	2	4/Yellow	Delay/Ignore
Risk 3	1	4	4/Orange	Address

Table 2. Enhanced risk approach in NPD using the IFAF as a modifier.

Risk Identification	Probability (Scale 1–5)	Severity (Scale 1–5)	IFAF (Scale 1–5)	Product (PxSxI)/Interv. Zone
Risk 1	3	5	0.2	3.0/Yellow
Risk 2	2	2	0.5	2.0/Yellow
Risk 3	1	4	0.3	1.2/Yellow

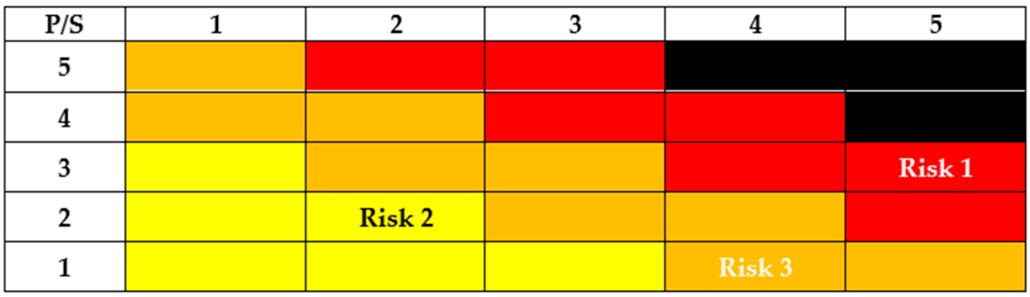

Figure 3. Visualization of the classical risk approach using a risk matrix (black—critical risk, red—high risk, orange—medium risk, yellow—low risk).

By adding a new evaluation dimension, related to the technologies, human factors, and AI instruments that can change risk perception or solution, the matrix becomes a three-dimensional space, where the three studied risks of the NPD process have considerably lower values and significantly changed positions in the risk space (Figure 4). Due to this modification, they can all now be considered tolerable risks, which can be tackled without the prior time and resources consumed for their classification and assessment.

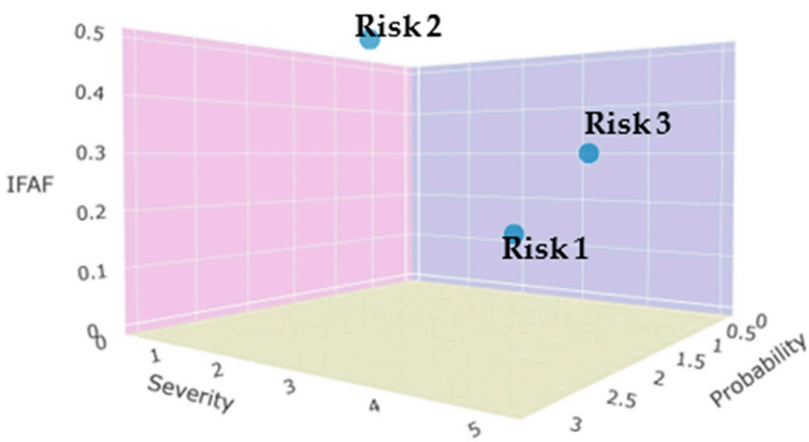

Figure 4. Visualization of the modified risk space using 3D Chart Maker [34].

From a mathematical point of view, the changes are simple, as the product (risk score) goes from two factors to three factors, as can be seen in Tables 1 and 2 and Figures 3 and 4. The method is more impactful on the graphical dimension, as the risk matrix in Figure 3 becomes a 3D graph in Figure 4 with the z-scale allocated to the IFAF. For the values of the IFAF, the following approach is proposed that considers possible courses of action when reducing the probability (more common) and severity (less common) of hazards.

The make-up of the IFAF and its value is highly dependent on the related concept of THAI, which is operationalized as a mind map of the most common elements encountered for each of its categories created with yEd (Figure 5). This presentation is a limited snapshot of the possible database of elements that fall under this definition and has the capability to influence risk treatment in significant ways.

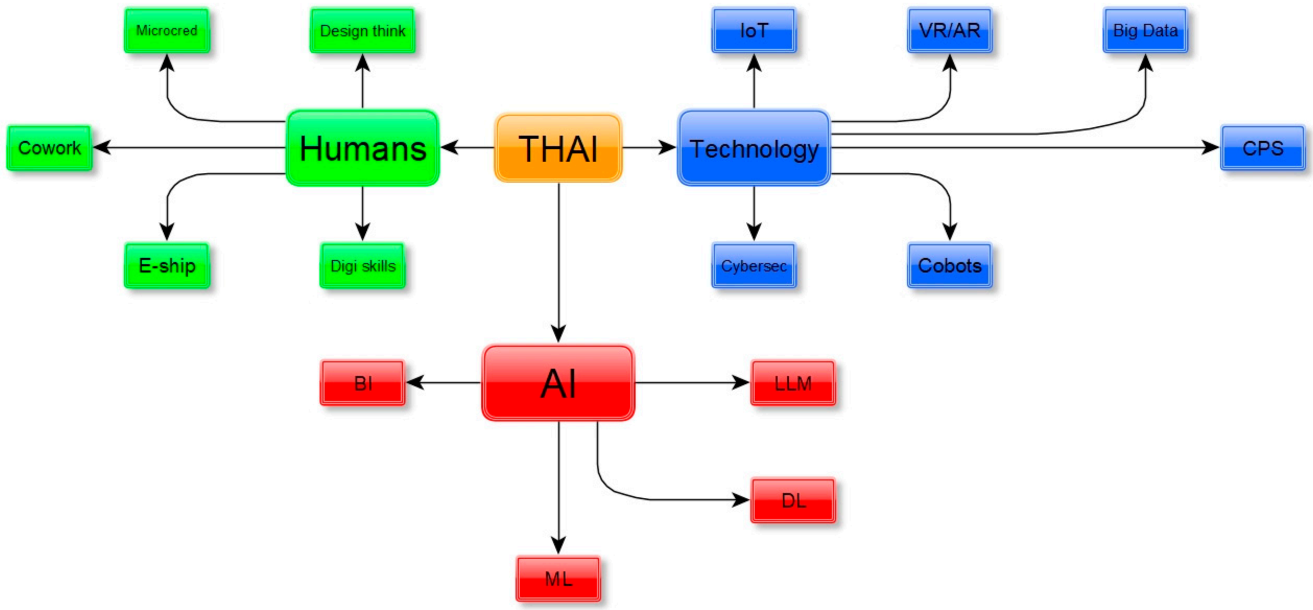

Figure 5. THAI concept definition by mind mapping (technological components in blue, human components in green, AI components in red).

In Figure 5 above, the three domains of intervention are detailed into workable tools and approaches, which impact the risk processing methodology. Each of the three zones is colored differently (blue for technology, green for humans, and red for AI tools), resulting in a mix of directly applicable instruments (e.g., BI—business intelligence), necessary investments (e.g., cybersecurity or cobots), and support measures to develop human talent (e.g., e-ship = entrepreneurship, microcredential schemes, or design thinking). The combined use of the IFAF and THAI is a qualitative intervention in the risk management and contingency planning process, and it is not meant to be performed continually but rather to periodically check for adherence to its principles from a historical perspective. The evaluation of the THAI factors should take place holistically, based on the experience of the company and the input of experts in the field of Industry 5.0 and AI, to determine the value of the IFAF on the scale presented in Table 3 and recalculate certain risks beyond the classical approach. It is possible, in the initial stages of deploying these technologies that will continue to impact the well-known probability and severity scores, for some risks to be overlooked and produce unwanted consequences, but with time, this should diminish to the point of disappearing and will be compensated by increased productivity.

Table 3. The proposed IFAF evaluation scale depending on the impact of THAI elements.

IFAF Value	IFAF Descriptor
0.0	Risk is completely removed
0.1	Some commonly unnoticeable risk elements remain
0.2	Some commonly noticeable risk elements remain
0.3	Risk probability considerably reduced; severity considerably reduced
0.4	Risk probability considerably reduced; severity slightly reduced
0.5	Risk probability is halved; severity is indifferent
0.6	Risk probability slightly reduced; severity slightly reduced
0.7	Risk probability slightly reduced; severity unaffected
0.8	Some commonly noticeable risk elements are removed
0.9	Some commonly unnoticeable risk elements are removed
1.0	Risk is completely unaffected

3.4. New Risk Approach Validation

The validation of the proposed risk approach was conducted in two steps. The first one included a semi-open interview with eight company representatives and the second one took the form of a case study, treating two different situations in the NPD process. This is a qualitative interpretation of the needed validation and should be followed by a more comprehensive quantitative evaluation.

The interviews took place in April and May 2024 and involved companies from the area of Cluj-Napoca in Romania involved in automotive, machinery and furniture manufacturing under the aegis of an important "Interreg Danube Region" project called Circular Innovation Hub-CI-Hub (https://interreg-danube.eu/projects/ci-hub, accessed on 31 May 2024), supporting SMEs to improve their innovation capabilities and adopt green and digital technologies in their NPD and manufacturing processes. A summary of the guidelines used for the interviews and the answers received is presented in Table 4 below.

Since this was conducted in a semi-structured manner, not all of the results are related and comparable to each other, but an important structuring of the undertaking can be achieved for future use. Elements of the transition from Industry 4.0 technologies to Industry 5.0 elements are detectable, and there is now no consensus on the actual benefits or feasibility in terms of risk management for the NPD process. The potential of the proposed approach is recognized and each element of it is accepted, but full integration is still difficult to accept. For this reason, the authors of this paper have also proposed a qualitative case study using two common situations that each of these companies has faced in their previous relations with their customers.

To evaluate the proposed approach, the authors have collaborated with a smart furniture-producing company, which has been developing a new product idea. This is focused on creating a smart desk lamp with an innovative design and digital features. The body of the lamp has a new creative shape, appreciated by potential customers, and makes use of a small quantity of solid wood with aluminum insertions to create an attractive combination. From a functional point of view, the lamp has integrated a capacitive touchpad for increasing the luminosity of its LED panel in four steps and an internet-connected weather station that relates the main information about environmental conditions through a wireless outdoor sensor (temperature, humidity, forecast) in addition to a calendar, clock, alarms, and reminders. The company manufactures the bi-material body and outfits the LED, touchpad, and weather station into the final product. The classical risk management approach has shown that the assembly of the aluminum insertions into the milled wood body presents a significant threat to the overall functionality of the product and could also influence the main selling point—a retro-futuristic design that hosts smart functions while providing the needed elegance for an office space.

Table 4. Guidelines for and results from the company interviews.

No.	Direction of Questioning/ Example Questions	Main Answers/ Resulting Discussion
1	Role, impact, and complexity of the NPD process. - what types of products do you develop? - what is their use by the customers? - what is the lifecycle of your products? - what regulations are impacting NPD? - how is the development process structured?	- the NPD process is mature and well understood - the results are expected to be price competitive - sustainability requirements must be addressed
2	Effort and resources committed to risk management. - what procedures are employed for risk management? - what measures/consequences are implemented? - how do the customers check your work/results? - what standardized methods are employed?	- risk management is mostly voluntary - classic approaches to risk management dominate the process and results analysis
3	Inefficiencies and redundancies of risk management. - how often is the process deficient/insufficient? - what number of person hours does it consume? - what is the impact of external requirements? - did you detect a learning curve in the firm?	- risk management is labor and time intensive - some companies have dedicated personnel - repetition is common
4	Main Industry 4.0 to 5.0 technologies adopted. - what advanced technologies do you employ? - what is their yield and return on investment? - are all capabilities fully utilized by NPD?	- IoT (collaborative), robotics, and machine vision are the most common - NPD integration is weak
5	Role and involvement of personnel in NPD. - what professional roles are engaged in NPD? - what type of expertise/competence is sought? - what is the level of autonomy of the staff?	- engineers almost exclusively engage in NPD - usual mechanical/ind. engineering background
6	Employment of AI instruments in NPD. - what AI instruments are used in NPD stages? - is AI work supplemented/corrected by humans? - is AI used for feedback from the production line?	- GPT tools are used to investigate ideas - media generation is used for visualization
7	Costs related to the possible new risk model. - can you estimate the release time/creativity? - can you compare costs vs. benefits? - do you need additional technologies or training?	- at least one person/company could be relieved - big data analytics is mandatory for NPD
8	Acceptance of the possible new risk model. - is the new approach understood fully? - do the personnel accept its use? - what are the main challenges for adoption?	- full-scale studies should demonstrate viability - personnel are interested, management is uneasy

Assembly issues have been rated at four on the probability scale and three on the severity scale (risk score is twelve), thus falling into the red zone and requiring significant mitigation actions. The selling issue has been assessed as two on the probability scale and five on the severity scale (risk score is ten), which is also in the red zone. Since both are related, the decision that the company is weighing is to replace the aluminum insertions with tampographic imitations made with a metallic powder-based paint that imitates the insertions and must be performed by an outsourcing company specializing in this process.

We present two excerpts from the applied tools (Figures 6 and 7) that can be used online and inline as the problems arise to provide robust solutions and continue the NPD process up to industrialization and future marketability.

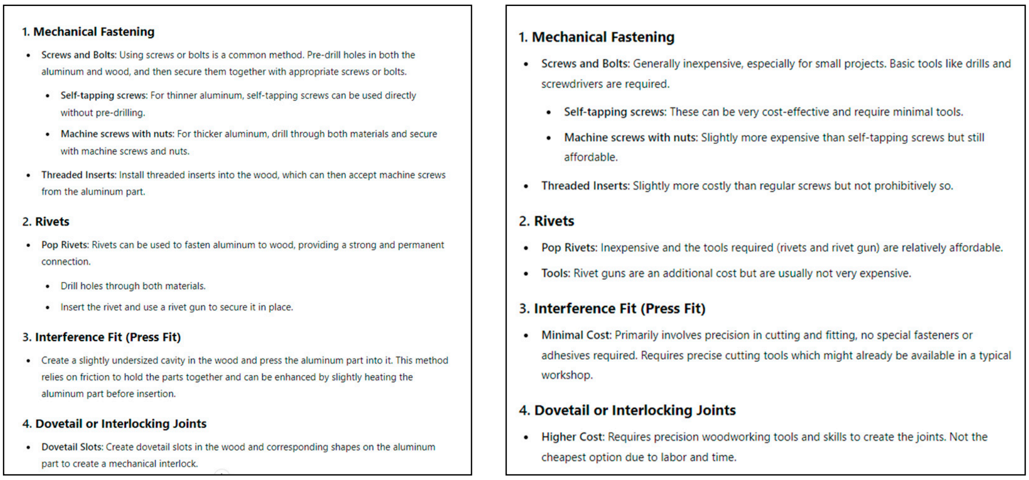

Figure 6. Open AI's ChatGPT recommending assembly techniques and analyzing their cost.

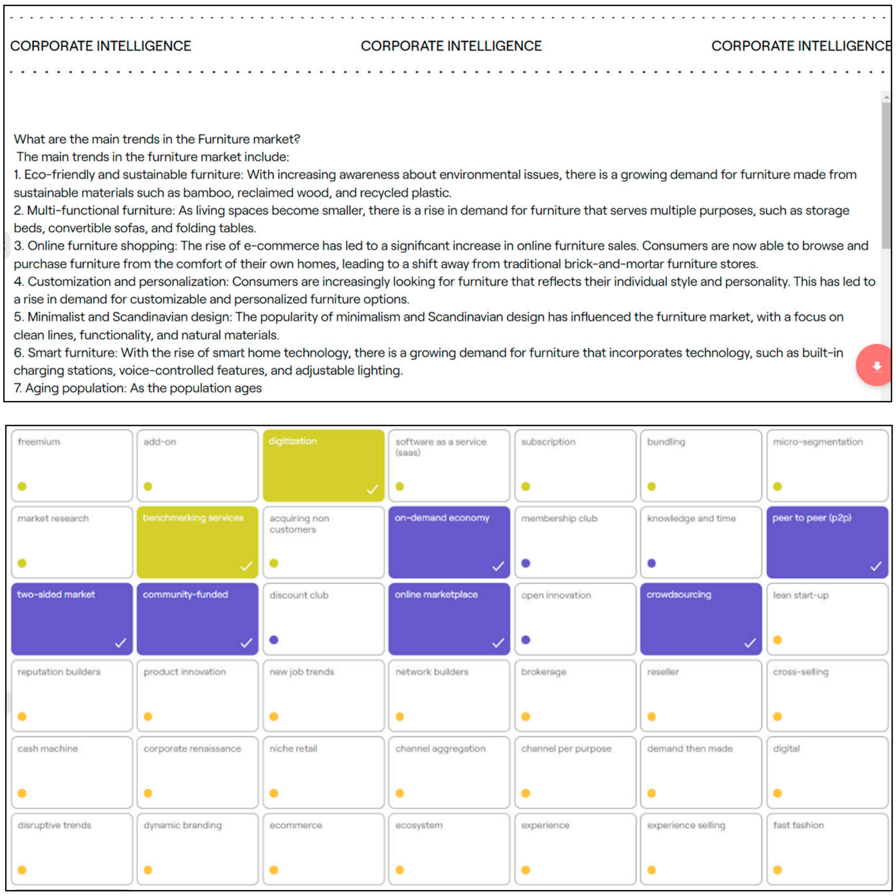

Figure 7. Vizologi analyses regarding competition and the business model.

In the modified risk approach, the company has employed large language models in the form of Open AI's ChatGPT-4 (https://chat.openai.com/, accessed on 30 May 2024) to discover alternative assembly techniques and Vizologi business intelligence (https://vizologi.com/, accessed on 3 June 2024) to refine the selling process based on the unique feature envisioned. Considering the use of these two AI instruments in conjunction with modern CNC equipment and highly trained personnel, as part of the THAI evaluation, the IFAF score has been set at 0.4, which would transform the initial risk score assessments into 4.8 and 4.0, respectively, making them manageable online.

The THAI solutions enable fast decision making when and if the problem arises, limiting the number of resources spent on forecasting risk and enabling the department head to make better use of the time of its members.

The following implementation procedure can be envisioned at this stage in the form of a set of guidelines to apply the currently existing components:

- Develop and implement the targeted production process as required by the company's business model (consider Figure 2);
- Deploy and assess the components of the THAI approach based on the development, digitalization, and investment strategy of the company (consider Figure 5);
- Periodically assess risks using the minimal classical approach of the risk matrix plotting probability and severity (consider Figure 3);
- Calculate the IFAF using the provided scale for online risk component mitigation (consider Table 3);
- Recalculate and compare the risk matrix integrating the IFAF and compare it with the initial version;
- If significant issues are identified, stop the process and reconsider the THAI factors, if not, continue with the process implementation and maturity and reallocate released resources to increase impact or revenue.

4. Discussion and Conclusions

The current work is focused on proposing a simpler approach to risk management in the NPD process, making extensive use of advanced technology, AI, and trained people. This is meant to serve as a more direct route to achieving fast results in manufacturing industries without cumbersome documentation and audit processes, internalizing the fact that the solutions available solve any possible negative events in almost real time. The definitions and evaluation procedures proposed here have been discussed with company representatives from the production sector in semi-structured interviews, revealing enthusiasm on the part of the design engineers and caution and apprehensiveness on the part of management. Still, in both cases, they welcome novel solutions to solve the current NPD anxieties related to the technical issues themselves but also the extensive risk management approaches. By qualitatively evaluating the THAI factors on the provided map (and its future extensions) and relating the established level to a quantitative score on the IFAF scale, the risk scores change drastically, and the contingency measures needed to be implemented fall mostly in the "recommended" section.

The situation encountered during the interview stage reveals, to a considerable extent, the efforts needed to popularize and clarify the capabilities of innovative technologies for product design and manufacturing in the proposed form or other similar ones. Also, the case studies performed show that the use of common or more specialized AI instruments can lead to significantly different decisions compared to the classical risk approaches, allowing the design team to maintain their design intent without making major changes due to manufacturing constraints.

It is advisable to consider the limitations of the current proposal, which conceptualizes a more philosophical approach to risk and seeks more validation in the various industries and various situations, both from a quantitative and qualitative perspective.

This study has been conducted in a single industry on a small sample of companies, to explore the validity of the concept. It is intended in the future to address different domains within the manufacturing and production sector and to interview a larger population of companies to derive more quantitively relevant information. Another limitation comes from the production engineering lens of this study that does not address ethical and social considerations, such as operator acceptability and workplace replacement risks, which are prominent issues that might influence the final effectiveness of the proposed method.

Moreover, since the components of the approach now are independent and scattered, a more cohesive integration into future risk management standards, procedures, and guidelines will serve to make the work of product developers easier. In this respect, however, there is no significant difference to the classical methods, which have also required a long time to become standardized and systematic. Another goal for future research is to translate this approach within a dedicated software instrument, which can take the form of an automated spreadsheet, a web platform, or a custom pretrained transformer, which would enhance its applicability to the production sector.

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