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Research Article

Business Model Generation for Industry 4.0: A "Lean Startup" Approach

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ABSTRACT

The emergence of the industrial internet of things that drives the fourth industrial revolution, also known as Industry 4.0 (I4.0), is bringing to the forefront the question of how industrial actors can capture value using such technologies. To answer this question, this paper follows a multidisciplinary approach drawing from the fields of Business Model (BM) Innovation and Entrepreneurship to create an agile process for generating and validating BMs that capture value in I4.0. By using tools and methodologies from these fields we are able to create a replicable process that bridges the cross-disciplinary gaps inherent in the new industrial landscape and generate models drawn directly from the knowledge and experience of industrial actors. Finally, using a version of the BM "Stress Testing" we identify risk factors and their effect on the generated models. By using said process, this work proposes, other than the process itself, several archetypes and four more specific BMs accompanied by stress factors and their impact. This paper hopes to provide industrial stakeholders with some basic tools and "roadmaps" to further test their models and create new ones, all in the prospect of establishing the elusive viable and sustainable "smart" factory ecosystem.

1. INTRODUCTION

Ever since its conception, Industry 4.0 (I4.0) came with the promise of revolutionizing the manufacturing status quo and creating innovative ways for factories to enhance their operations and value proposition [1–3]. Although concepts like "Smart Factory", "Cyber-physical Systems", "Internet of Things" and others have been repeatedly explored in academia [4], manufacturers still struggle to pioneer radical innovations and capture real value through technological excellence [5,6].

Manufacturing firms exhibit typical "incumbent inertia" [7] toward these technologies mainly in terms of not formulating an adequate value-creation strategy along with business models that differentiate oneself from the competitors. Innovation remains of prime importance in achieving sustainable efficiency and competitive advantage in manufacturing [8]. Our research is focused on the process of business model generation as a way improving manufacturer's responsiveness to new technologies [6,9]. As depicted in Figure 1, generating innovative Business Models (BMs) can create actual value rather than focusing on stand-alone technologies.

Business Model Innovation (BMI) concerns the firm's core business rather than specific products. It is not solely regarded as an agent of 'innovating the existing processes' whose purpose is self-evident. In fact, BMI has a profound impact on a company's "DNA" and requires far-reaching changes. Essentially, firms' processes that have been followed and internalized for years, relatively well in most cases, must be altered in order for a BM to succeed. As with all data driven business models, a new BM design approach is essential that centers around the customer while at the same time clearly differentiating between said customer and the end user [10]. Despite the recent growth in BM literature [11] there is limited empirical evidence on how manufacturing companies adapt their models [12] in the face of disruptive I4.0 innovations. Against this background, the central research question that motivates this paper is to generate different business models that are relevant to the I4.0. To address this goal and the aforementioned gaps, our specific steps are:

- To conceptualize BMs for I4.0 and validate them.
- To examine comprehensively the uncertainties that inhibit the ability of manufacturing companies to innovate their business model when they are challenged by the arrival of I4.0 technologies.
- To explore how startup tools can be applied to the context of business model generation for I4.0.

Our effort is based on an exploratory and qualitative case study design, within a research project that allowed us to get unique insights directly from the industry and come up with BMs that best address the needs of actual stakeholders. The remainder of this paper is structured as follows. Section 2 discusses related studies while Section 3 describes the research approach. Section 4 presents the process followed to generate the BMs and identify relevant "stress factors" [13]. Finally, Section 5 presents four BMs for various roles/stakeholders within the I4.0 ecosystem and Section 6

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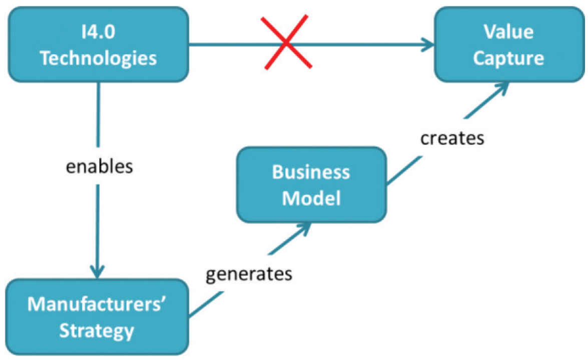

Figure 1 | Business Model Generation as an enabler to capture value from emerging technologies.

summarizes the main findings and the limitations and signifies some recommendations for further research.

2. RELEVANT WORK

Industry 4.0 exists as a concept for several years [14] and is based on long-standing technologies. Still, it remains essential for companies to adopt new BMs that will allow the seamless adoption of innovations brought forth by I4.0 technologies, and lead to higher chances of market success [15,16]. However, current research focuses on the technological implications of I4.0 [17–19] rather than the business model with which a firm can capture the added value offered by the new technologies.

In parallel, BM innovation has been gaining a lot of traction, boosted by the prevalence of new (digital) technologies, evolving markets, and changing customer demands [20]. BM innovation is regarded as increasingly important both in terms of creating a viable competitive advantage but also as a means toward a viable new business venture [21]. The last decade saw a flurry of publications, enhanced by the expanding global entrepreneurial ecosystem, that shifted the focus from traditional extensive and strict Business Plans, to lean and agile BMs [15,22]. These works not only created a variety of BM generation tools but also expanded our understanding of what constitutes an innovative BM and how it can be applied to transform traditional business: "Agile" and "Lean" methodologies have become commonplace for emerging companies that need to conceptualize and pinpoint their operations' BM [23,24].

Even though, the concept of "Lean Startup" is increasingly used in business strategy, the "Lean philosophy" has its origins in manufacturing [25]. Ries [26] and Blank [27] brought the lean philosophy and its principles to the startups' development area [28]. Lean startup involves listing the assumptions of a BM and testing the riskiest ones. Lean startup emphasizes a customer-centric orientation under conditions of extreme uncertainty [26]. Furthermore, the idea that you do not execute a BM but rather look for one is at the heart of the lean start-up approach [27]. This is why the BM generation tools that will be discussed in this chapter were extensively used in the startup ecosystem. All the above make lean startup a fitting approach for the novel I4.0 technologies.

While the relevance and importance of new BMs for I4.0 is evident through-out contemporary literature [17,29–31], our review revealed a limited number of specific BMs that can be implemented as-is by I4.0 stakeholders. In this context, we should highlight the work presented in four different papers that try to tackle this gap in specific BMs, albeit via different routes than our work. Weking et al. [19] centers around the creation of a taxonomy for BM archetypes in I4.0 using a literature review that resulted in 40 different use-cases; their result is a high-level mapping of BM elements found in I4.0. Ibarra et al. [32] also deploys a review in order to identify features, issues, and requirements that affect I4.0 BM and through this process presents four different variations of Value Creation–Value Delivery–Value Capture sets, that can be used to gain different benefits from I4.0. Moving closer to our approach, the work of Bagnoli et al. [33] presents a structured review analyzing the importance given by the literature to the technologies and their impact on the single building blocks of the BM. Finally, Kiel et al. [34] approach the connection between Industrial Internet of Things (IoT) and BMs by researching the interrelations between BM elements and the changes brought forth in said elements.

Considering the lack of specific, market-validated BMs for I4.0 and the ever-expanding research around BM generation, this article tries to use lean startup methodologies to create and test new BMs for I4.0 firms, whether they are manufacturers, technology providers, or brokers of a 360° platform for manufacturers. BM concepts can promote understanding of a firm's inner working and pinpoint how I4.0 delivers value to the customers via a suitable revenue and cost model [31]. Building the previously mentioned research, we aim to use entrepreneurial methods to generate I4.0 related BMs taking into account external factors that affect each BM element, using a replicable process.

In order to conceptualize and present BM for I4.0, we are using insights form several strategic management and lean startup tools or templates such as the Business Model Canvas (BMC), the Value Proposition Canvas (VPC) [22], the St. Gallen BM Navigator and the BM "magic" triangle [15] plus the Cambridge BM Innovation Process [35], all combined and used in two "hothouse" idea generation workshops, that are designed under design thinking principles [36]. We consider the documentation of this end-to-end approach on the domain in hand as important on its own regarding its replication in further studies on manufacturing.

3. RESEARCH DESIGN: AN EXPLORATORY CASE STUDY

Our objective of exploring BM generation as a response to manufacturers' inability to capture value from I4.0 technologies lacks prior systematic research, hence yielding as appropriate an exploratory and qualitative multiple case-study research. Theory building from case study is suitable for unexplored areas, in which the researcher's proximity, both conceptually and physically, to the underlying phenomenon, allows for deeper engagement with the social settings [37]. The case study is based on our involvement in the Horizon 2020 funded project DISRUPT,[1] which aims at a platform combining all the core elements (e.g. event processing, cyber-physical system, cloud board and controller, etc.) for a full

[1]"Decentralised architectures for optimised operations via virtualised processes and manufacturing ecosystem collaboration", funded from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723541.

I4.0 solution. Our participation in the DISRUPT project helped us receive direct feedback by various I4.0 stakeholders whether manufacturers, software providers, integrators, or research centers (the list of participants can be found on Table A1 in Appendix). This also presented a set of challenges, as the cross-disciplinary gaps among such actors raised quite different understandings of how a firm does and/or should work, ascribing different importance to different elements [38]. To mitigate this problem, we designed a design-thinking process bridging the cross-disciplinary gap and effectively gathering data and feedback.

We used several data sources: (a) a review of relevant research and academic papers (b) semi-structured interviews with selected firm representatives and academics (c) questionnaires for participating firms, and (d) the completed business strategy templates from a series of workshops. To create high-level archetypes, we conducted a brainstorming workshop were partners from all collaborating entities combined their expertise to fill in a set of VPCs and BM "magic" triangles for DISRUPT's potential outcomes. These canvases served as a first step in forming a more complete idea of what industrial IoT BMs look like.

We also conducted two sets of interviews with firm executives about the firms' strategy, obstacles, and key strategic actions with regard to the implementation of I4.0 technologies. The first set was an open, round-table discussion that covered high-level strategic issues and problems that their companies and the consortium face when implementing industrial IoT. The second focused on specific individuals with in-depth knowledge of their firms' inner workings and models on the basis of the initial BMs that we had generated up to that point. The purpose was to identify specific strengths and weakness of the said BMs and how they could be implemented or adapted for their firms. Our goal was to understand the mechanics behind major bottlenecks (e.g., the power of certain stakeholders) as well as alternatives that could be considered (e.g., using different channels and suppliers).

Finally, an online questionnaire was created and circulated amongst the participating firms to evaluate the effect that different stress factors have on elements of the BMs, were they to be implemented in their company. The aim was to map the importance of the various issues that we had gathered up to that point and see their effect on different BMs from varying perspectives.

Even though the cases that drive this paper are limited (less than ten organizations), the purpose of this research is to answer "how". To that end we opted for a more theoretical (not random or stratified) sampling. Consequently, cases are selected because they are particularly suitable for illuminating and extending relationships and logic among constructs [39].

4. THE BUSINESS MODEL GENERATION PROCESS

This section analyzes the stages followed to generate relevant BMs. It also provides the necessary information to ensure the applicability and replicability of our approach in similar contexts. We also highlight a set of "stress factors" that can adversely affect the implementation of industrial IoT.

All the material gathered across the various stages is partly confidential and could be provided upon request.

4.1. Pinpointing Relevant BM Archetypes – Stage 1

The first step aimed to map how entities that aim to use I4.0 technologies identify their needs and opportunities. The objective of this stage was to conceptualize future desired BMs in a structured and explicit way. To do so, we conducted a brainstorming workshop with the involved stakeholders inspired by the nascent entrepreneurship acceleration process [40] and BMI [41]. We also used tools such as the Value Proposition Canvas [22] and BM "magic" triangles [15] as BM mapping tools for the workshop.

In order to enable a more fruitful discussion, the project's various modules/technologies were organized in three different groups. Each group was representing a different exploitation possibility and a viable alternative product steaming from DISRUPT: The Data Analytics, Decision Support Tool, and Cloud Controller.

The focus of this workshop was on different value offerings in order to identify, how different products and/or services stemming from DISRUPT could create value for various stakeholders across the value chain. This exercise was also important in order to identify different customer segments that could be targeted by different DISRUPT technologies.

For the workshop itself, the participants were arranged into three distinct groups based on background and project roles (i.e. each group had academics, technical and businesspeople). Each group was assigned to one of the three products. We proceeded with conducting two "creative sprints". The first was aimed at identifying relevant customer segments and filling-in the VPC. The second sprint revolved around creating new BMs using the BM "magic" triangles. During the first creative sprint each group was asked to identify potential customer segments for their assigned product in no more than 5 min, then they were given 15 min to fill in the VPC for the identified customer segments. After this process the completed VPC was passed to the next group which added comments through a fresh perspective (as they had worked on a different module) repeating the same process clockwise until every group has been through every VPC. A similar process was followed in the second "creative sprint". Each group was asked to fill-in the BM triangles and as before after 15 min the documents were passed on to the next group which added their comments and suggestions. In the end every team had 5 min to pitch their ideas and explain their rationale behind each document.

At the end of the first workshop, we gathered a set of VPCs for each module and another set of BM triangles that described different models that could be applicable to DISRUPT.

4.2. Literature Synthesis and Review – Stage 2

While an initial literature review was conducted before Stage 1, Stage 2 updated that work and combined it with the insights previously generated. In this stage we analyzed the gathered data and cross checked them with the "55+ BM patterns" from the St. Gallen Business Model Navigator [15] which helped us identify ten different BM patterns for different modules that serve as high level archetypes.

Table 1 | Business model patterns for module groups

BM pattern	Project module		
	Data analytics module set	Decision support tool set	Cloud services
Digitalization			X
Hidden revenue			X
Leverage customer data	X		
License	X	X	
Pay per use	X		
Prosumer	X	X	X
Sensor-as-a-service	X		
Solution provider	X	X	
Subscription	X	X	X
Virtualization		X	X

This identification was possible by matching specific elements ascribed by the project partners to the different modules with elements of the BM patterns in Gassmann et al.'s work. This process resulted in 10 different BM patterns being identified for I4.0 actors that were categorized as depicted in Table 1.

4.3. Refining, Evaluating, and Validating BMs – Stage 3

The objective of this stage was to gather feedback on the archetypes created and identify uncertainties (Stress Factors) that can hinder the implementation of I4.0 BMs in established actors.

As such, at the second workshop we used the generated material in order to create three different BMCs for roles within DISRUPT and the I4.0 ecosystem. This time the focus was not on specific value offerings but on the potential actors themselves, namely the manufacturers, technology providers and the integrated platform as a whole. This process had two steps: The first was to identify problems, potential risks and stress factors for the created BMs, and the second was to gather all these elements, group them and return to the project partners to evaluate the factors' impact on specific BMC building blocks.

To this end, the project partners were presented with three BMs (in the form of BMCs). After an open discussion on how these BMs would work for each stakeholder, participants were asked to write down a set of their thoughts on each BM and what in their opinion would work or not, based on their experience and expertise.

Following this session, several key personnel from different organizations were interviewed in order to get more in-depth insights on how these BMs could be implemented by their organizations, what other risk/stress factors could affect this implementation, and how the answers gathered on the previous session could affect their specific BM. The people interviewed came from the majority of organizations involved in the project. The interviews, while recorded, were conducted under a confidentiality agreement, in the spirit of due academic process and in order to enable respondents to answer freely as they were asked sensitive questions including their companies inner-workings and strategies, and their countries legislative and governing mentalities.

The second workshop provided us with three sets of results. First, we put together a list of elements that can hinder the implementation of I4.0 BMs in established actors. These so called "stress factors" can be summarized in six broader categories as follows:

- Management issues: Lack of prioritization or support by top management, corporate culture, and rigid organization.
- Economic issues: Unclear economic benefits, excessive investments, competing in-house programs.
- Technological readiness: Low maturity level of required technologies, information and data security issues, non-seamless integration, and ineffective data management.
- Lack of trained personnel: Insufficient trained personnel in company/region, inadequate in-house knowledge.
- Unclear standards and regulations: Lack of industry standards, contradicting regulations in different regions, data ownership issues.
- Power of other stakeholders: Powerful actors across the supply chain, resistant to change ecosystems.

This work not only verifies previous research and assumptions on I4.0 coming both from business [42,43] and academia [44,45], but it also expands on them by adding several new elements that managers should take into account. Second, the open discussion and semi-structured interviews provided us with unique insights that were essential to create a more specialized BM in the next stages.

4.4. "Stress Factor" Ranking – Stage 4.1

After creating the initial BMs and gathering the set of factors that can affect them, we had to turn back to the people from the industry and ask them how severely these factors could affect the generated BMs. To do so, we circulated a questionnaire that allowed respondents to rank the importance of various stress factors with regard to different elements of the proposed BMs.

The questionnaire was based on Bouwman's BM stress testing methodology [13,46]. Using this methodology, "Heat Maps" were produced to indicate the impact of a specific stress factor on a BM component (potential showstopper/positively influence of the feasibility or viability) and consequently the general BM robustness.

The robustness was ranked via a questionnaire, where respondents ranked the impact of specific factors on a scale of 1 (no impact) to 7 (very high impact). The answers were group and are presented with the following color coding: 1 – no impact (white), 2 and 3 – low impact (green), 4 and 5 – average impact (orange), 6 and 7 – high impact (red). The BM heatmaps can be found in Appendix. More detailed matrices with numbered responses can be provided upon request.

4.5. Calibration and "Advanced BM" Creation – Stage 4.2

During the final stage of the process we consolidated all the gathered data to create a fourth BM (Data Marketplace) that could match the partners' needs and requirements. Due to project time constraints this stage took place almost in parallel to stage 4.1.

4.6. BM Generation Process Summary

To summarize, this section presented a process that can be used to generate and stress-test new BMs in interdisciplinary systems, such as the I4.0. To do so, interested actors can follow the five stages previously analyzed. First, they need to gather data in order to identify archetypical BMs that are relevant to their operations. We propose this being done through workshops (see Subsection 4.1) that involve a variety of disciplines and departments from a project to ensure diversity of opinions. The second step would be to gather this data and see which BM archetypes are the best match, using a blueprint like the St. Gallen Business Model Navigator [15]. After that, one needs to re-address the departments involved and ask them to identify problems that would be created or that would hinder the application of these BM. This would allow to go to the fourth step which would be to present a mapping of this business model with all the important factors that accompany needs to be aware of and their severity. Finally, they can go back to the start and redesign BMs that take into account what they have learned throughout the process. As this is an agile process, repeating it a couple of times can lead to even better results. The overall process to generate and validate I4.0 BMs is shown in Figure 2.

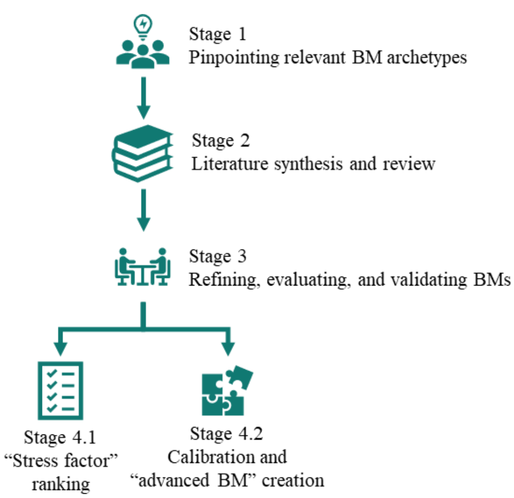

Figure 2 | Methodological steps.

5. VIABLE BUSINESS MODELS

Using the workshop process described previously we generated four BMs in total, three of which are tested under the BM stress test methodology. This allowed for an initial validation from industrial actors on problems for specific BM elements that can hinder their implementation and essentially test the BMs' robustness.

5.1. Manufacturer

In the context of DISRUPT the manufacturers were Fiat Chrysler Automobiles (FCA) and ARCELIK, both large scale producers, between the two of which a large variety of different products is created. Moving forward with "smart" manufacturing, entities like FCA and ARCELIK, would have to implement a large number of structural changes in order to remain competitive and fully implement an IoT driven production environment. As such, this BM explores how a manufacturer would function under the I4.0 premise (Figure 3).

5.1.1. Manufacturer business model highlights

- Operates in two layers: Classic and IoT enhanced.
- Servitization elements.
- Potential for leveraging production data.
- New customer segments.
- Managing relationships across the supply chain is crucial.
- Suppliers must adopt new technologies for maximum benefit.
- Traditional business at the core (e.g. an automotive factory will still sell cars) innovation at the edges (added value to core through data centered services).
- Existence of "Prosumers".

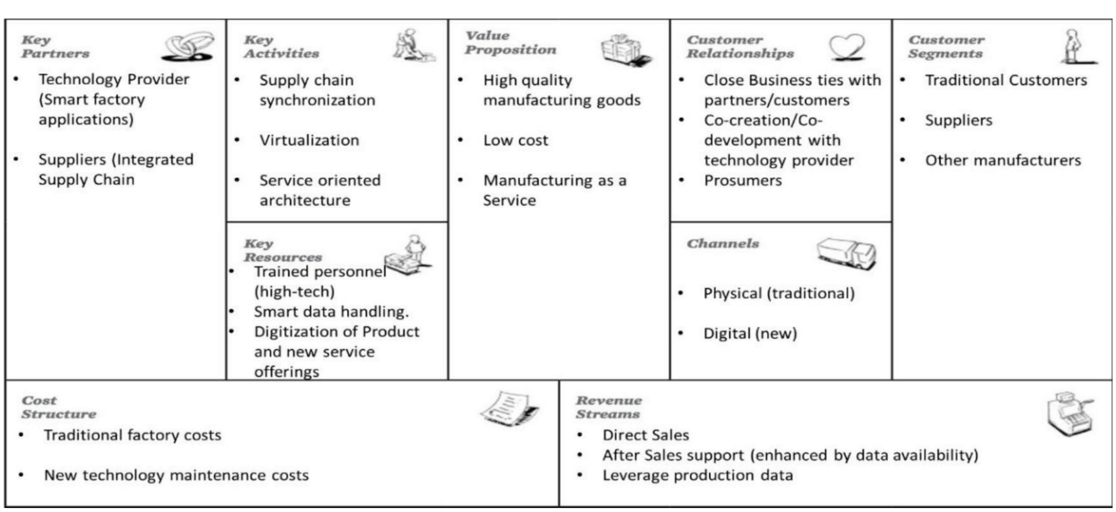

Figure 3 | The manufacturer business model.

5.1.2. Business model stress testing

Comparing the stress test results (Figure A1) with data from the other BM heatmaps and the information gathered through the interviews and open discussions, we can suggest that economic and managerial issues are comparatively more impactful. There is also an important risk of how to monetize the new services and fit this new stream to existing revenue models. Finally, comparing the answers of the two organizations we can suggest that "Technological Readiness" seems to be the least important stress factor. This would also be in accordance with responses for the rest of the BMs as can be seen further on.

5.2. Technology Provider

The technology provider profile and BM concerns entities that exists in the manufacturing supply chain and provide technological solutions (e.g. software, analytics, cloud services, etc.) for other actors in I4.0. They do not necessarily have to provide a whole platform, but rather technological elements that are essential for a "smart" factory (Figure 4).

5.2.1. Technology provider business model highlights

- Deviates from the traditional Software-as-a-Service model in terms of revenue streams and customer relationships.
- Closer relationships with actors across the supply-chain.
- Lifelong partnerships, co-creation and co-development of services.
- Ability to leverage customer data (manufacturer or end-user).
- Possible co-creation schemes with manufacturers.
- Process/Sensor-as-a-Service revenue streams.

5.2.2. Business model stress testing

The most important stress factor (Figure A2) for the whole model is, not unexpectedly, the various economic issues. Throughout the BM elements in about 50% of the answers, economic issues are perceived as of extremely high importance. Following with Bouwman et al. [13] classification, these elements can become "showstoppers" if not managed correctly.

Another factor that needs to be carefully addressed are the standards and regulations governing the industrial internet. While not a "showstopper", respondents seem to agree that it should be carefully considered closely, as in almost 80% of the responses it was marked as of either medium or high importance. This issue was also reaffirmed during the one-to-one discussions and also by other concurrent similar research, as the regulation around data management and handling (especially data as a tradeable commodity) is continuously changing. Lack of industry standards are also a big source of uncertainty especially as the current standards are inadequate to enable the new capabilities brought forth in the sector by the adoption of IoT.

Examining the BM blocks, projects partners assign the most risk, regardless of stress factor, to the Key Activities. This means that a Technology Provider's most important value adding activities are highly susceptible to various factors. As such, this identifies an important stress point for this BM that needs to be addressed.

Our research also uncovered several interesting correlations between BM elements and stress factors. More specifically, management issues seem to have very high impact on the customer relationships, a fact that highlights the importance of a well-defined central policy and vision for addressing new and current customers when making the shift to an I4.0 BM. Economic issues, while generally important, seem to also have extremely high impact on customers (as customer segments).

Finally, one of the most important building blocks for the new BMs, the revenue streams, is considered to be considerably impacted by management and economic stress factors, decidedly more so than any other stress factor.

5.3. Platform-as-a-Service

This BM deals with the integrated platform, designed as a product. Under this model, a company would provide a platform for

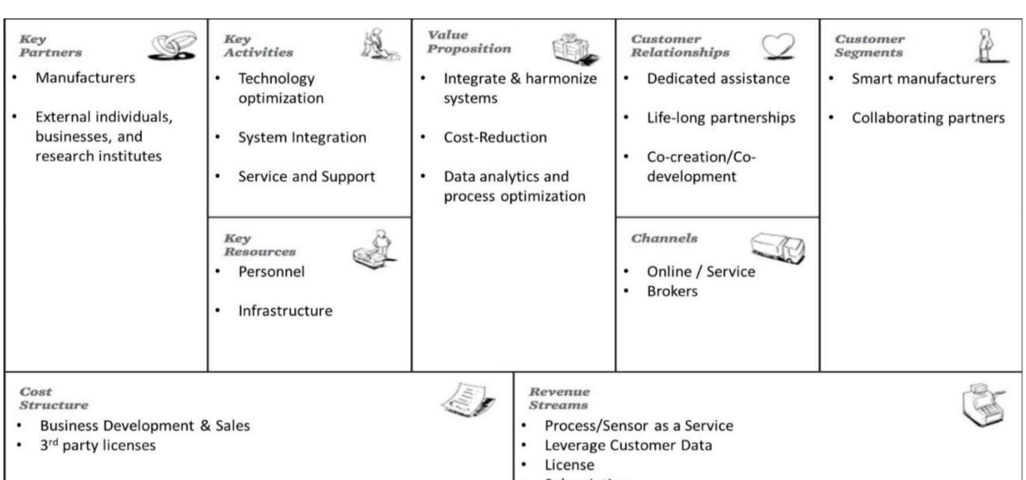

Figure 4 | The technology provider business model.

I4.0, that would act as a plug-and-play solution for relevant parties across the value chain (Figure 5).

5.3.1. Platform-as-a-service business model highlights

- All-in-one solution for industrial stakeholders.
- Emphasis on seamless integration, virtualization, and visualization.
- High technological readiness and adaptation.
- Close relationship management.
- Customer engagement and communication is of high importance.
- Accessibility to massive amounts of data across the value chain that can be leveraged.

5.3.2. Business model stress testing

As with the previous BMs, respondents for the integrated platform consider economic issues amongst the most important stress factors (Figure A3, Figure A4) for the BM (43% of total answers mark it as high impact). Even more so, economic issues, seem to be showstoppers for the customer segment and revenue streams BM elements.

What is interesting is that the lack of trained personnel is perceived to be both of very high importance (43%) and of low to no importance (44%). It is also interesting that respondents of different backgrounds answer consistently differently on this stress factor. An explanation for this discrepancy could be that company roles (manufacturer or technology provider) and different locations can adversely affect the access to specialized personnel that would implement an integrated platform. It is however important to note that high impact answers from "Lack of trained personnel" are mainly concentrated around the "Key Partners" and "Key Activities" BM element. This finding pinpoints a potentially important insight as respondent are cautious of the effect that unspecialized personnel could have on how their partner relationships are handled. If this claim can be corroborated it highlights an important risk as partner management and satisfaction is crucial for the integrated supply chain required to create a "smart" factory.

Generally, the riskiest BM element seems to be the "Key Partners" block. This is in line with all discussions and relevant literature as the "integrated platform" BM is based on the premise that value and information is shared across the value chain and that all stakeholders are essentially partners amplifying data value.

Lastly, another BM element that most respondents agree is impactful is the "Channels" element. Clearly, as channel management is part of how a company deals with its supply chain, communication, collaboration, and sharing of value is crucial for the success of an integrated platform BM.

5.4. Industry 4.0 Data Marketplace

Based on the three previous BMs and drawing from the data gathered we drafted an "advanced" BM that generalizes the use of I4.0 data. The I4.0 Data Marketplace deals with stakeholders that could be organized inside a platform to help them sell and buy data, creating value from the availability of otherwise unorganized, unattainable data. An actor with this BM could facilitate other I4.0 players who are not ready or able to use the data they produce themselves acquire a new revenue stream. So, if, for example, a manufacturer sets up all the sensors and systems but is not yet able to analyze the data (or they just want the extra revenue), the data owner could sell the data through this facilitator. On the other end, a technology provider who wants to create new services specific for I4.0 but does not have access to the required data themselves can buy them through the marketplace. Essentially the Data Marketplace, created through the needs and insights of project participants, reaffirms the findings presented at the Manufacturer BM and further stresses the potential for new revenue models and value offerings created by the industrial IoT (Figure 6).

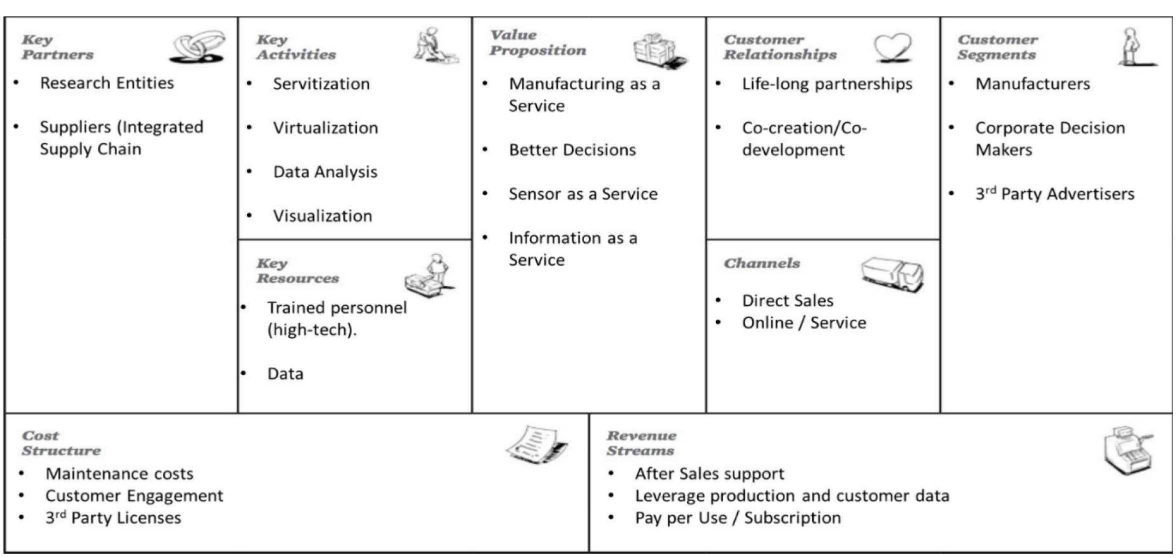

Figure 5 | The platform-as-a-service business model.

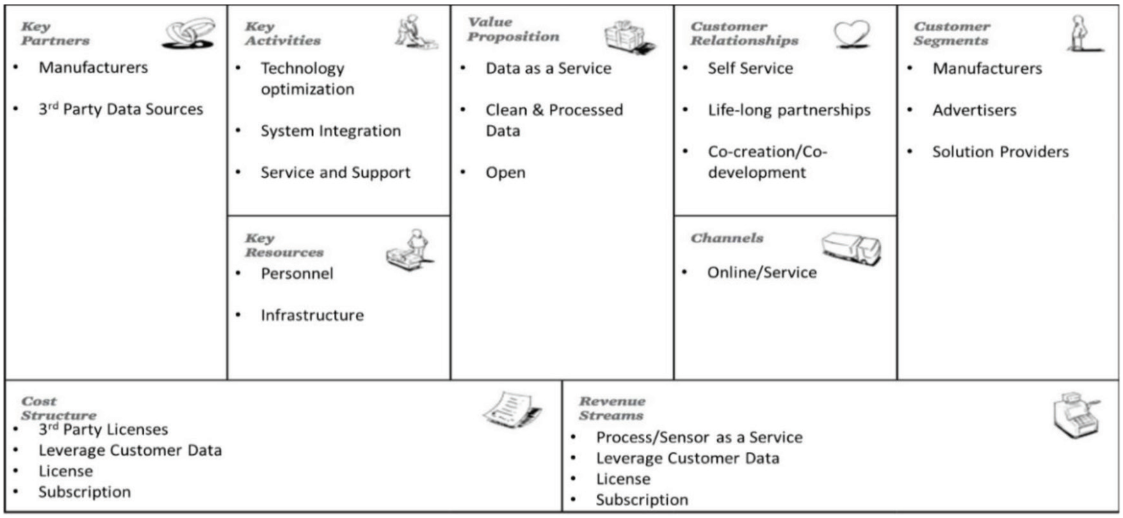

Figure 6 | Industry 4.0 data marketplace business model.

6. CONCLUSION

The rapid growth of I4.0 technologies has the potential to revolutionize the status quo of many manufacturing firms and entire industries. Despite the unleashed potential by these technologies, manufacturing firms fail to pioneer radical innovations and they apparently find it difficult to capture real value. Looking at the maturity levels and readiness of I4.0 technologies, their ability to respond to disruptions is not just a question of having the technology by itself. Even back in the 90s there were for example sensors in machines, so those concepts have been around for a while. Today, it is more a matter of creating added value for the end consumer and innovating the traditional BMs to differentiate from the competitors.

The overall objective of this research was, therefore, to gain more knowledge about the process of business model generation as a new direction towards the manufacturing firms' responsiveness to capture value from I4.0 technologies. To address this objective, the research design was based on an exploratory and qualitative case study within a Horizon 2020 funded project. Participating in the project helped us to obtain exposure to manufacturing companies at a level of detail required for achieving a deep understanding of the process of business model generation when they are challenged by the arrival of I4.0 technologies.

6.1. Theoretical and Practical Implications

This study may have a significant impact not only for academics but also for practitioners in manufacturing. First, this paper extracts 10 different BM archetypes based on Gassmann et al. [15] as high-level concepts applicable to I4.0, and a set of four different BMs for specific stakeholder roles based on Reuver et al [20]. While these BMs can be further refined and tested, they are amongst the first ones in this context to cover all elements relevant to the value creation for the most important actors within the I4.0 value chain.

Taking a step forward, this research offers the adaptation and utilization of the BM "stress" test methodology proposed by Bouwman et al. [13,46]. It adopts the stress/risk factors in order to test the robustness of the proposed BMs. As a result, it identifies 17 different risk factors, organized in six groups, that can hinder the adoption of I4.0 technologies. While a list of such factors has already been identified both in academia and business (e.g. [42,44]), we enrich this list through interviews and discussion with large enterprises that will play a key role in the real-life application of I4.0 technologies. This process resulted in verifying part of said list and adding several new elements to it.

Another interesting outcome is that this research proposes a five-stage process that can be used to generate and stress-test new BMs in interdisciplinary systems, such as the I4.0. Using lean startup tools inspired by the nascent entrepreneurship acceleration process [40] and BMI [41], the paper signifies an effective dialog between manufacturers and technology providers. The manufacturers are the domain experts and have a detailed knowledge of the manufacturing processes, their inefficiencies, and the I4.0 technologies' potential for improvement. On the other hand, the technology providers can understand what I4.0 technologies can offer and then design the supporting infrastructure and software. Together, they seek to develop an innovative BM. Hence, apart from helping us in I4.0 BM generation, we consider this process as a first step toward further exploring the possibility of a streamlined methodology to communicate and share information across disciplinary barriers.

6.2. Limitations and Future Research

Although this work provides valuable conclusions concerning BMs for I4.0, it is nevertheless subject to a number of limitations.

The study focuses on specific case studies as part of a research and innovation project. Aiming to present BMs validated by industry actors even if they are theoretical in nature, it is important to further validate the BM patterns to a bigger sample, especially manufacturers. The BM robustness results offer important insights mainly for the technological side of the I4.0 equation, but are inconclusive where the manufacturers are concerned, as our respondents are large-scale and innovative but diverse.

On creating the heatmaps, we opted to slightly adapt the process and have higher-level stress factors as this served better the stakeholders' purposes. Our suggestion for further research is to break down the stress factor grouping that we created and have more I4.0 companies rank the BMs. Moreover, further work is also needed to validate the five-stage process and demonstrate its potential strengths or weaknesses.

We also provide evidence on BMs for I4.0 by looking at each component of the BM separately. This implies that the manufacturing firm should obtain a 'system view' of the effect of 'local' changes in the model, allowing for the identification of implicit dependencies between components of the BM. A snapshot of one part of the model is likely to underestimate the impact of I4.0 technologies and this limitation signifies some recommendations for further research.

Finally, this paper supports the idea that the integration of I4.0 technologies within manufacturing processes should not be assessed as a stand-alone investment. This implies a transition from one BM to another. "When evaluating an initial investment, the value of a potential second stage investment has to be considered as an added value to the first stage project" [47,48]. Otherwise, the value of the initial project can be underestimated. As a result, we argue that the BMs for I4.0 should not only be assessed in isolation but also as a bundle of sequential investments. Applied to this study, this idea is of practical value in the sense that a manufacturing firm that wants to invest in I4.0 technologies should maintain a longer planning horizon, meaning that the BM can be implemented in sequence (pivoting) as initial and future investments.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

AUTHORS' CONTRIBUTION

SB, AK, and IM propose the use of "Lean Startups" tools and thinking, to be utilized in the context of I4.0 to create novel BMs. SB and AK provided a review of relevant literature and formulated the methodological background. Interviews, workshops and data gathering was conducted by SB and IM and then analyzed collectively by the authors. IM supervised and coordinated the process.

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APPENDIX

Table A1 | Participating organizations

Organization name	Country	Categorization
CENTRO RICERCHE FIAT SCPA/FIAT CHRYSLER AUTOMOTIVES	Italy	Manufacturer
ARCELIK A.S.	Turkey	Manufacturer
SOFTWARE AG	Germany	Technology provider
ATHENS TECHNOLOGY CENTER S.A.	Greece	Technology provider
BOC ASSET MANAGEMENT GMBH	Austria	Technology provider
SIMPLAN AG	Germany	Technology provider
THE UNIVERSITY OF MANCHESTER	United Kingdom	University/research center
CONSIGLIO NAZIONALE DELLE RICERCHE	Italy	University/research center
ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS	Greece	University/research center

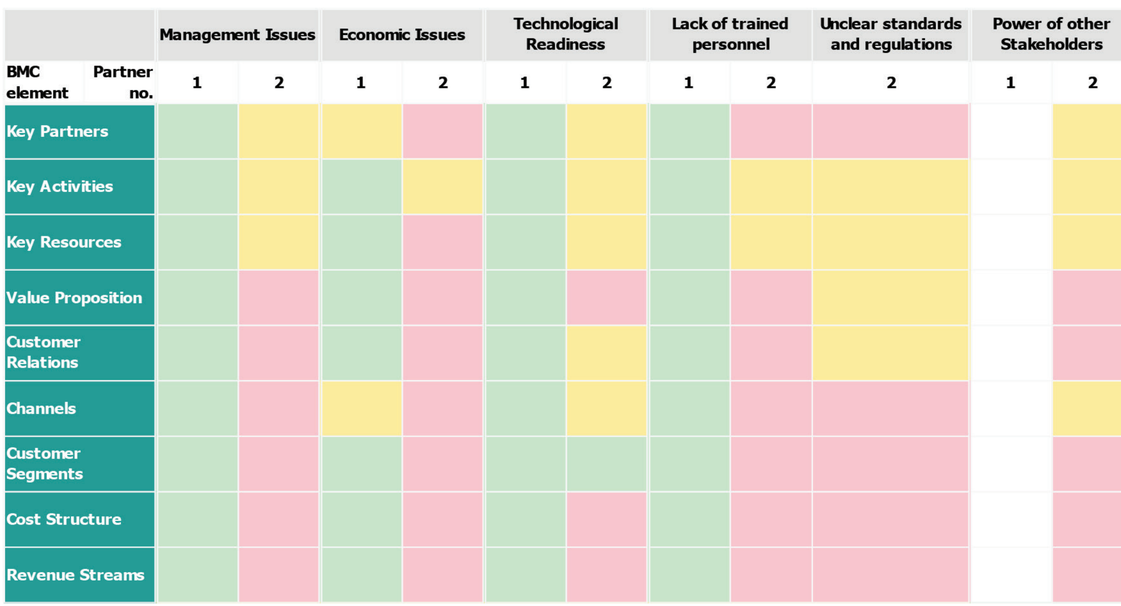

Figure A1 | The manufacturer business model stress test.

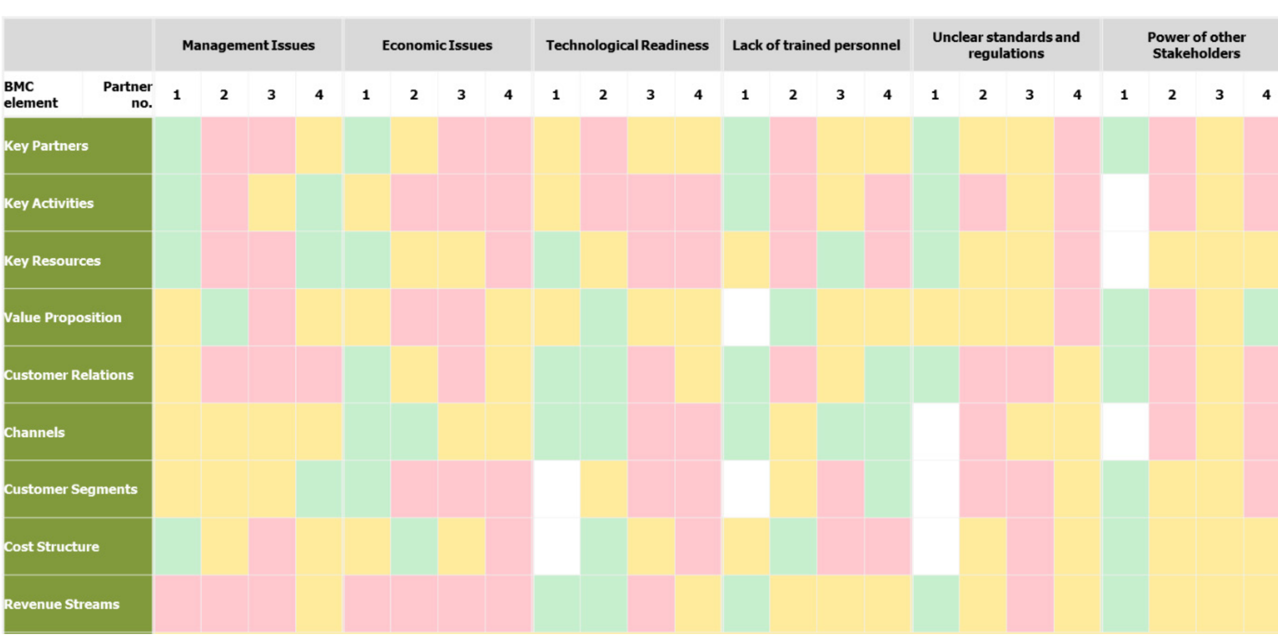

Figure A2 | The technology provider business model stress test.

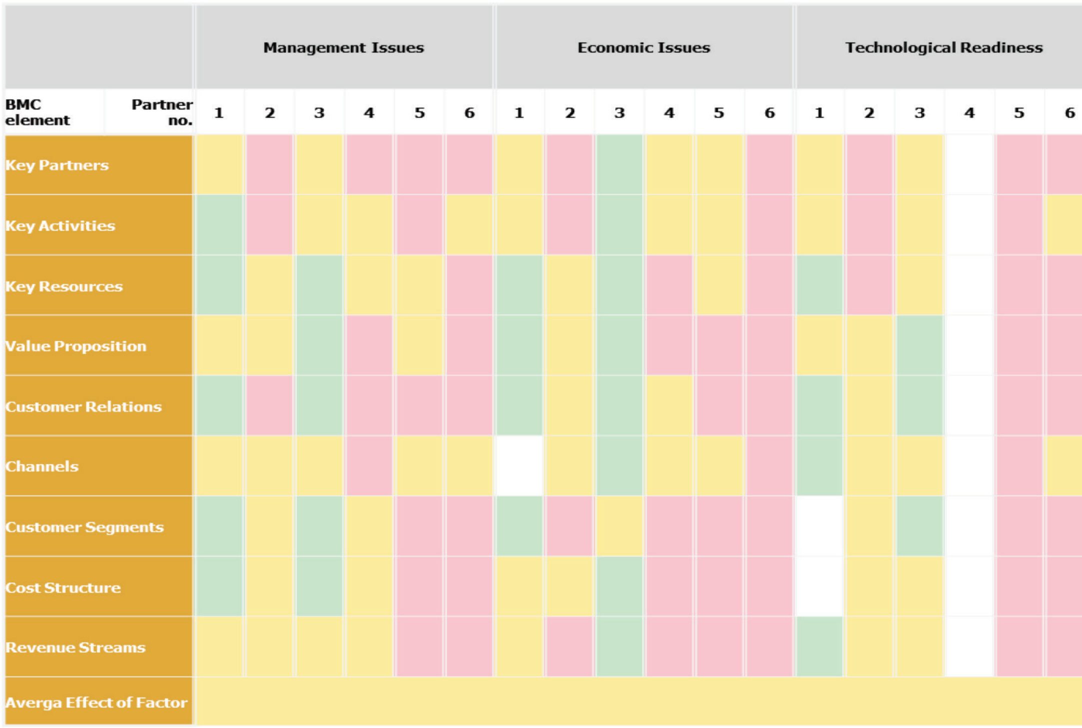

Figure A3 | The integrated platform business model stress test 1/2.

Figure A4 | The integrated platform business model stress test 2/2.