

Research Article

Implementation of Frugal Innovation Approach in Moroccan Industry through the Development of a New Frugal System

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Received 17 September 2023; Revised 2 December 2023; Accepted 29 January 2024; Published 19 February 2024

Academic Editor: Himadri Majumder

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To keep pace with economic growth in an environment marked by globalization, competition, and the significant magnitude of market requirements, companies must be dynamic to adapt quickly to new demands. This dynamism must be achieved through frugal projects aimed at achieving better performance with fewer resources. In line with this vision, we have proposed a new frugal innovation approach to develop a new concept of machines to meet the requirements of Smart Automation, which is the main element of the transformation plan defined by our company as a strategy for the coming years. This strategy aligns with the direction set by Morocco for the second generation of the Industrial Acceleration Plan 2021–2025. This work serves to introduce the objectives of the second-generation Industrial Acceleration Plan in Morocco, describe a company transformation strategy with an emphasis on the Smart Automation component and its context, explain frugal innovation applications within our organization and their outcomes, and outline the project and frugal innovation approach perspectives in Morocco. The results demonstrate the effectiveness of the newly proposed and implemented concept of frugal innovation, illustrated in a cost reduction of 59.7% compared with the manual process, of less than 56.3% compared with the existing semi-automatic process, and of less than 36.8% compared with the fully automatic process and in the improvement of quality by a reduction in customer complaints of 72.7% and in the scrap rate percentage of 0.2%. This has been achieved by providing cost-effective solutions in our competitive automotive environment. These results reinforce the importance of the approach in its global application.

1. Introduction

In an environment marked by globalization, competition, and the significant magnitude of market requirements, companies must be dynamic to adapt quickly to new demands and seize opportunities. Therefore, the success of any company depends on its ability to respond in an evolutionary way to the needs of its customers, especially in the automotive sector where competition is constantly increasing. This requires rigorous organization, effective production management, efficient resource utilization, and continuous performance improvement.

To keep pace with economic growth, Morocco launched the Industrial Acceleration Plan (IAP) in 2014 to consolidate business productivity and ensure value chain integration [1]. The IAP is structured around ten strategic axes, with the fifth focusing on improving the competitiveness of companies. The key challenges include increasing inclusive company competitiveness, attracting investments, and fostering innovation (efficiency, innovation, and financial accessibility). After consolidating the achievements of the first plan, Morocco has launched the second generation of the Industrial Acceleration Plan for 2021–2025. This new plan aims to consolidate industrial development on a national scale by creating new sectors, implementing measures to encourage research and innovation, promoting technological capabilities, supporting the adoption of innovative production methods for Industry 4.0, and ensuring the preservation of natural resources in Morocco [2].

To effectively respond to multiple challenges, anticipate changes, be responsive, and keep pace with the evolving landscape, companies aim to enhance the performance of their processes by minimizing inputs and maximizing output. They also strive to ensure a continuous improvement process. In this context, our company is dedicated to meeting its customers' needs under any circumstances, aligning its objectives with the goals of the second generation of IAPs 2021–2025. This commitment is manifested through the launch of the mega project "Transformation Plan."

The plant transformation project primarily consists of four components: Smart Automation, Business Understanding, People Development, and Agility Development. The Smart Automation component relies mainly on new machines, emphasizing the optimization of resource utilization, increased output, and improved return on investment for projects, all while proposing innovative solutions at reduced costs. To successfully realize this vision, we have embraced the frugal innovation approach. This approach is founded on accessible principles that facilitate adaptation to various conditions, with the ultimate goal of achieving superior performance with fewer resources. The proposed approach aims to develop machines with frugal solutions for producing cables at the lowest cost while maintaining cable quality. The developed machines exhibit high competitiveness in terms of technical solutions, budget allocation, and return on project investment.

The aim of our work is to develop a frugal concept to produce data transmission cables within an industrial company. We have achieved an ecosystem through this frugality, which will ensure production at the lowest cost and at a high level of performance in terms of output, system process capability, scrap rate, reduction in customer complaints, and reduction in space used. The performance of our frugal system was evaluated in relation to the company's strategic objectives and compared with other existing systems within production.

This work serves to introduce the objectives of the second-generation Industrial Acceleration Plan in Morocco, outline our company's transformation plan with a focus on the Smart Automation component and its context, present the application of frugal innovation at our company through the proposed frugal approach, and list the project and perspectives of the frugal innovation approach in Morocco.

The remainder of the article is organized as follows: Section 2 summarizes the objectives of the secondgeneration Industrial Acceleration Plan in Morocco. Then, in Section 3, we describe our company's transformation plan with a focus on the Smart Automation component and its context. In Section 4, we highlight the frugal achievements of our company and their outcomes. Section 5 presents the conclusion, project perspectives, and the frugal innovation approach in Morocco.

2. Industrial Acceleration Plan in Morocco

2.1. Industrial Acceleration Plan 2014–2020. The launch of the National Plan for Industrial Acceleration 2014–2020 follows the initiation of the first mega project called the National Industrial Emergence Pact in 2009, which, in turn, succeeded the Emergence Plan of 2005. The goal of the 2009 National Pact was to rejuvenate the Moroccan industry, aiming to create 220,000 jobs in urban areas, generate an additional industrial GDP of 50 MMDHS, and increase exports by about 95 MMDHS. The national pact for industrial emergence has a focus on several sectors, including automotive, aeronautics and space, offshoring, textile and leather, and agri-food [3].

The National Plan for Industrial Acceleration 2014–2020 is defined as an integrated catalyst for growth, with a focus on creating efficient ecosystems. Established in 2014, the Industrial Acceleration Plan aims to consolidate the productivity of companies and ensure the integration of value chains [2]. Aligned with the Emergence Plan, it seeks to transform the sector into a significant growth level. This industrial acceleration program targets several ecosystems, including the automotive industry, aerospace, textile and leather industries, chemicals and parachemistry, heavy vehicles and bodywork, construction materials, and pharmaceuticals [4, 5].

The objectives of this plan are as follows: to increase the industry's contribution to GDP, enhance export capacity, reverse the trade balance, boost the absorption capacity of new assets, increase productivity through targeted industrial support, and improve the capacity to attract investors. Under the new industrial plan, the industry aims to achieve the following broad objectives by 2020: the creation of 500,000 jobs, with half stemming from foreign direct investment (FDI) and the other half from the updated national industrial infrastructure. In addition, the industrial sector aims to raise its GDP contribution from 14% to 23% by 2020 [6, 7]. To achieve the outlined objectives, the new approach is represented by three classes in Figure 1: industrial ecosystems to promote greater industry integration, supporting tools designed for the industrial sector, and a stronger competitive international position.

2.1.1. Industrial Ecosystems to Promote Greater Industry Integration. Reducing sectoral fragmentation and creating a more interconnected industry are the objectives of the first set of initiatives. This initiative focuses on the development of industrial ecosystems intended to establish new dynamics and relationships between major organizations and SMEs [8]. As part of the implementation of these ecosystems, special attention will be paid to supporting the informal sector in its transition to the formal sector. This includes the introduction of a comprehensive system for integrating very small businesses (TPE), which involves establishing the category of "auto-entrepreneur," creating a customized tax structure, providing social protection assistance, and offering special funding [7].

2.1.2. Supporting Tools Designed for the Industrial Sector. The IAP offers a range of integrated measures to provide tailored support to firms and create a favorable framework for developing their activities, addressing the critical issue of increasing SMEs' competitiveness. The Industrial Development Fund (IDF), a state industrial investment fund with a budget of 20 billion dirhams, aims to help the industrial sector consolidate, modernize, and enhance its capacity to



FIGURE 1: Three axes of the National Plan for Industrial Acceleration 2014-2020 [7].

substitute imported goods. In terms of industrial land preparation, 1000 hectares will be allocated for the establishment of industrial parks with complete rental facilities. These industrial parks, in addition to the existing industrial zones and integrated industrial platforms, will include a onestop shop, a local job pool, ad hoc services, and a training system [7, 9].

2.1.3. A Stronger Competitive International Position. The third set of actions aims to enhance Morocco's international standing. Regarding its position in external markets, accompanying efforts will focus on industries with strong export potential to strengthen the competitiveness of the kingdom's exportable offerings. The strategy also aims to open Morocco to global market development opportunities, such as the announced relocation of 85 million Chinese jobs, by fostering a culture of deal-making. A dedicated team has been put in place to achieve this. Finally, the IPA proposes measures to realize Morocco's African vocation, which has been emphasized at the highest level of the state. Privileged relations with African partners will be strengthened in the context of mutually beneficial cooperation [7].

2.2. Industrial Acceleration Plan 2021–2025. After motivating results of the National Plan for Industrial Acceleration 2014–2020, another boost is given to the Moroccan industry with the launch of the National Plan for Industrial Acceleration 2021–2025. The main goal of this plan is to build upon the achievements realized during the first phase of the plan and extend them to all regions by integrating small- and medium-sized enterprises (SMEs) and placing the industry at the center of technological transformation [3, 10, 11].

This new plan, developed and implemented in partnership with the regions, focuses on strengthening and integrating Moroccan capital in the industry and promoting the creation of new sectors for marketing and product development, with a strong emphasis on the regional dimension. This approach aimed at ensuring industrial development on a national scale, as outlined by the Head of Government on December 30, 2019, in Rabat [12].

The second generation of the Industrial Acceleration Plan (IAP) 2021–2025 also aims to advance technological capabilities, research, and innovation by introducing new systems geared toward the future and adopting new manufacturing techniques from the 4th generation of industrialization. In addition, it places a strong emphasis on the preservation of Morocco's natural resources [13].

2.3. Conclusions from the Development Plans of the Moroccan Industry. Since 1980s and until 2021, when Morocco launched the second plan of Industrial Acceleration for 2021–2025, Morocco has gone through different policies and strategies in line with the state of the economy and the issues related to each period. In early 1980s, Morocco aimed to resolve the identified problems by focusing on an export promotion strategy. From 2005 onwards, Morocco experienced a turning point in its industrial policy model, shifting towards the implementation of a trade-based strategy, which is considered as one of the most dynamic sectors in world trade [5].

In 2014, after noting the insufficient progress in terms of competitiveness and the low contribution of industry to growth and employment, Morocco launched a new industrial policy known as the "Industrial Acceleration Plan 2014–2020." The plan aimed to position the industry as a key driver of growth. This structural transformation initiated by Morocco has been furthered with the launch of the second plan for Industrial Acceleration 2021–2025. This plan will expand on relevant objectives to strengthen the industry in various aspects, including research and innovation and the creation of new sectors, all while ensuring the preservation of the country's natural resources.

At this stage, and in alignment with this structural transformation, we considered incorporating our frugal approach to innovation within the Moroccan context. Our aim is to contribute to this significant industrial transformation and provide frugal solutions for both existing and newly emerging situations arising within the framework of the transformation plan's objectives. The philosophy that drives frugal innovation is to create an inexpensive, versatile, and sustainable solution at a reasonable price within constrained conditions. In this perspective, as the automotive sector presents a strong opportunity for innovation, and to achieve our company's plant transformation objective of developing ecosystems and low-cost solutions to improve competitiveness, it was decided to use frugal innovation to create a frugal system for producing data transmission cables, which would include frugal solutions at each station level.

The creation of ecosystems is the first axis of the national Industrial Acceleration Plan, focusing on the development of industrial ecosystems designed to establish new dynamics and relationships between large organizations and SMEs. In implementing these ecosystems, particular attention will be paid to supporting the informal sector in its transition to the formal sector. The proposed approach is applicable to the components of the Industrial Acceleration Plan, and consequently, we have established a correspondence between the objectives of the Industrial Acceleration Plan 2021–2025 and the contributions of the frugal innovation approach as described in Figure 2 [14].

3. Transformation Plan Project

3.1. Introduction. The project for developing a frugal concept using the frugal innovation approach is presented. The work was conducted within our industrial company, which operates in the automotive sector, specializing in cable assembly for car manufacturers. The need we addressed was identified within the broader company strategy, and we gained the confidence of the administration to embrace the spirit of frugality while implementing this approach. This came after a thorough examination of the strategy's objectives and its pillars. Ultimately, we successfully aligned our approach with certain pillars of the company's strategy to create a frugal system that effectively addresses the operational challenges faced by the company.

3.2. Introduction to the Transformation Plan. The transformation plan is an extensive project initiated by our company to enhance the overall performance of the factory. Its goal is to achieve this growth by addressing the strategic components with direct and indirect connections to production. The transformation project seeks to enhance the factory's efficiency and create a significant value by implementing direct actions on the production processes, as well as by enhancing the support functions to sustain and reinforce the factory's performance.

During the process of this transformation, the procedures and work instructions have undergone minor and radical changes in various elements. In terms of actions, the Transformation Project is advancing with an approach based on the proximity of the partner, cost-effective solutions, and flexibility in solutions. The transformation plan is structured around four main axes: Smart Automation, Business Understanding, People Development, and Agility Development.

3.3. Transformation Axes. The transformation strategy is constructed around the following primary axes to achieve its objectives: Smart Automation, Business Understanding, People Development, and Agility Development. Our work is at the core of the Smart Automation axis; therefore, we will place more emphasis on this axis. Figure 3 illustrates the elements covered by each axis, aiming to provide a comprehensive overview of the transformation and underscore the significance of Smart Automation as a crucial technical aspect of this strategy. To develop a sound strategy, the four transformation axes were evaluated based on the criteria described in Table 1. This assessment aims to define the scope and parameters that will be encompassed by the transformation plan's axes, generating significant benefits when the transformation project is implemented. The assessment criteria were chosen to cover important aspects and achieve representative results.

The scope aspects and application fields mentioned in Table 1 differ in their contributions to the primary axes of the global transformation plan. In this work, three aspects, Technical Knowledge Build-Up, Innovative Spirit Build-Up, and Activity Digitalization, are emphasized due to their strong connection to our own Smart Automation axis. With this orientation, we will apply our frugal innovation approach to achieve efficient optimization and make a meaningful contribution to the factory's strategy.

3.4. Transformation Goals. Our company's transformation plan aims to attain direct and measurable objectives, as well as generate several benefits and advantages for the plant. The goals of this transformation involve shifting from the operational to the strategic level. Figure 4 illustrates the four objectives outlined in the transformation plan, namely, improving plant efficiency, reducing the scrap rate and the number of customer complaints, and achieving a 20% increase in flexibility.

In addition to the objectives mentioned above, the transformation plan aims to bring about significant improvements in terms of the working environment. The key points of this vision are as follows:

- (1) Creating a safe environment for employees and partners
- (2) Adapting the management system to the new organization and priorities
- (3) Fostering the autonomy development of Shop Floor Leaders
- (4) Motivating, recognizing, and nurturing team ambitions
- (5) Promoting an open discussion forum for addressing relations, expectations, and feelings

3.5. Frugal Application: Projects and Results. To align with the transformation plan's objectives, our company's team is dedicating efforts to develop a new concept of cable machines aimed at enhancing the Smart Automation defined by the company as a core component of its strategy. In pursuit of a significant advantage in terms of cost-effective solutions, which is one of the goals of the transformation plan, we have proposed a frugal innovation approach to create a new concept equipped with both new and existing solutions for producing various cable configurations. The choice of frugal innovation is based on the mindset of the approach, which aims to provide an economical, flexible, and sustainable solution at an affordable price under constrained conditions. From



Objectives of Industrial Acceleration Plan 2021-2025

FIGURE 2: Contribution of frugal innovation to achieve the objectives of the Industrial Acceleration Plan 2021-2025 [12].



FIGURE 3: Transformation plan axes: The strategy of the transformation plan is built upon four axes linked to processes, business, people, and agility.

TABLE 1: Transformation plan and evaluation criter	insformation plan and evaluation cr	iteria
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Study aspects	Smart Automation	Business Understanding	People Development	Agility Development
Organization autonomie	×	×	×	×
Management system adaptation	×		×	
Training and coaching in the shop floor	×		×	×
Technical knowledge build up	×		×	
Innovative spirit build up	×	×	×	×
Activities digitalization	×			
Supply chain design				×
Internal prototype center development	×	×		

this point of view, and to achieve the transformation objective of developing ecosystems and low-cost solutions to improve competitiveness, it was decided to exploit frugal innovation to develop a frugal system to produce data transmission cables, consisting of frugal solutions at each station level.



FIGURE 4: Transformation plan goals: The goals are defined in four points, with three related to the production process and one linked to the customer.

3.5.1. Smart Automation. The concept of frugal innovation involving frugal solutions resulted in a semi-automatic machine. The choice of concept and the level of automation was made after a thorough comparison of various concepts, including manual, semi-automatic, and fully automatic options. Table 2 illustrates why the automation solution was selected, with the decision being based on several criteria.

3.5.2. Automation Level. In addition to the manual and automatic processes, there is a medium process known as semi-automatic, with each type being used according to specific needs. Sometimes, it is preferable to find a simpler solution that achieves the same result at a much lower cost and does not require an advanced maintenance system [15, 16]. The transition from a fully manual to a fully automatic process involves passing through the levels of automation depicted in Table 3 [17]. For levels 2 and 3 of automation, we have the following:

- (1) Allowing operators to move on and add a value while the machine works
- (2) Allowing multiprocess handling instead of waiting
- (3) Ensuring a high level of flexibility
- (4) Requiring lower capital investment compared to fully automatic machines

Levels 4 and 5 of automation, known as "THE GREAT DIVIDE," are characterized by

- (1) significant capital requirements to meet the specifications of the machines
- (2) high levels of technical complexity
- (3) loading and transferring parts, which facilitate tasks for operators
- (4) process reliability often below 90%

In addition to the details mentioned in Table 3, the decision to choose this concept takes into consideration the

availability of partners, their position, and their responsiveness to our company's requests, as well as all aspects related to the proposed frugal concept, such as raw materials, space parts availability, and required skills. Ultimately, we have decided to proceed with level 3 of automation.

3.6. Introduction to Both New Concepts and Old Concepts

3.6.1. Products under Study. The product under our study is a coaxial cable, specifically a bipolar cable. These cables consist of an inner conductor surrounded at regular intervals by an outer conductor that is hollow and cylindrical. Its primary function is to shield the internal conductor from radiation originating from parasitic sources. The cable's resistance to line waves and its damping characteristics as a function of frequency are determined by its construction [18]. To prepare the cable for use, terminal and connector components will be added to both ends to facilitate the female/male connection during utilization. Figure 5 illustrates an example of the product's construction [19].

3.6.2. Innovation Frugal Definition. In terms of the solutions proposed for building the new concept, frugal innovations are the approaches used to provide the required responses to the expressed needs. The term "frugal innovation," as defined by Tiwari and Cornelius Herstatt, refers to innovative services and products that "seek to minimize the use of material and financial resources across the value chain in order to reduce the cost of ownership while meeting or exceeding certain predefined criteria of acceptable quality standards" [20].

Frugal innovation, as described by Bhatti, Y.A. (February 1, 2012), might encompass both methods and outcomes, resulting in overlapping perspectives. It can be used to describe low-cost innovation methods such as reverse diffusion [21], reverse engineering, do-it-yourself, creative improvisation, jugaad, and design processes, as well as the utilization of methods like open-source methodology. According to BusinessWeek (2009), jugaad is a form of improvisational innovation driven by a focus on customers' current demands rather than their lifestyle and limited resources [22, 23].

3.6.3. Innovation Frugal Principles. Frugal innovation principles were first defined by Radjou and others as a way for achieving innovative solutions in challenging environments, such as the developing world [24]. The following principles are applicable in different areas; the adaptation of each principle depends on the situation, nature, and constraints of the environment. The applicability of the principles is not linked to each other, and they can be used separately to achieve the good results.

Seek opportunity in adversity: Frugal innovation entrepreneurs see the situation's limits as an opportunity to produce cost-effective solutions. Adversity presents an opportunity for alchemists to add value. To flourish, any business must be able to innovate in the face of adversity.

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	Manual assembly	Semi-automatic assembly	Fully automatic assembly
Customer requirements	0	++	++
Product quality		++	++
Cycle time	0	+	++
Investment in euro	+	+	+
Operator cost/year		+	++
Flexibility	++	++	+
Space		++	+
Changeover time	+	++	+
Material flow	0	++	++
Safety	—	++	++

TABLE 2: Transformation plan and evaluation criteria.

 \rightarrow Rating, ++ = fits perfect, + = good solution, 0 = neutral, -- = unfavourable, and -- = improper solution.

	Load machine	Machine cycle	Unload machine	Transfer part
1	•	-	-	
2	-	Auto	-	-
3	-	Auto	Auto	-
		The great divide		
4	Auto	Auto	Auto	-
5	Auto	Auto	Auto	Auto

TABLE 3: Automation level [17].



FIGURE 5: Processing cable example. The product is a coaxial cable with a specific technology at the extremity [19].

Doing more with less: Doing more with less contrasts sharply with the West's "more is better" R&D approach, which has failed to make essential services such as education and healthcare more affordable to more people. Indeed, this frugal philosophy can assist enterprises in both emerging and mature economies in optimizing the use of finite financial and natural resources while providing high value to a broader number of customers.

Think and act flexibly: Frugal innovation is the opposite of structured methodologies like Six Sigma. The flexible mindset of frugal innovation entrepreneurs continually questions the current quo, keeps all options open, and alters existing goods, services, and business structures. Frugal innovation innovators can respond fast to unforeseen changes in their surroundings since they are not restricted by organized methods. Frugal innovation innovators do not just think outside the box, they invent entirely new ones.

Keep it simple: Frugal innovation is not about striving for sophistication or perfection by overengineering products, but rather about creating a "good enough" solution that gets the job done. Creative simplicity is the key principle of frugal innovation.

Include the margin: Frugal innovation seeks out marginalized, underserved customers and brings them into the mainstream. Such frugal innovation creates radically affordable solutions to satisfy the demands of these underrepresented markets. Their inclusive business ideas engage low-income and unconventional groups not as passive consumers but as active value cocreators.

Follow your heart: Frugal innovation focus groups and formal market research are not used by inventors to choose what goods to create. They are intimately acquainted with their consumers and their products, and they ultimately trust and follow their hearts. Frugal innovation entrepreneurs use intuition, empathy, and passion-qualities that are increasingly vital in navigating a global world as analytical thinking.

The companies can adopt frugal innovation by following the two points shown in Figure 6 [24].

3.6.4. Applications and Success Stories of Frugal Innovation Approach

(1) Renault–Nissan Frugality Application. Renault–Nissan CEO Carlos Ghosn, who widely coined the term "frugal engineering" in 2006, is challenging his French and Japanese engineers to match, if not outperform, their Indian counterparts in terms of cost, performance, and speed. Renault is fast increasing the portfolio of its low-cost Dacia brand, which includes the hugely successful Logan car, which sells for under \$10,000, by adding the Logan van, Logan truck, and even the Dacia Duster SUV. Aimed at budget-conscious



FIGURE 6: Getting started with frugal innovation.

European car purchasers, these no-frills Dacia automobiles, manufactured in Renault's Romanian facility, use fewer parts and have a simplified design while remaining affordable and strong. Renault CEO Carlos managed to manufacture a frugal vehicle in a frugal plant by transferring frugal engineering to Morocco via the Renault-Nissan factory setup.

(2) Morocco against COVID-19 Pandemic. During the COVID-19 epidemic, Morocco displayed a remarkable response to satisfy requirements at multiple levels: social, economic, and health. Under the idea that necessity is the mother of invention, inexpensive innovations were conceived and implemented in a Moroccan climate known for limited resources, as well as the extremely short time frame required by the COVID-19 pandemic. The radical change in the activities of the manufacturing companies to produce the masks needed, the flexible solutions proposed by those concerned, and the cooperation of the population in coping with this pandemic have enabled Morocco to guarantee its independence from other countries and to ensure the safety of its country in the near future.

(3) Moroccan Hydrogen Production. Following the findings of the study, which indicated the existence of a high potential for growth of this field in Morocco, a strategy for the development of green hydrogen in Morocco has been implemented. Morocco has the capacity to absorb up to 4% of the global market demand for green molecules. The Moroccan hydrogen production is organized around three major key areas: technologies, construction of an industrial cluster and development of a matching infrastructure master plan, as well as leading to fresh ventures.

3.6.5. Choosing the Frugal Innovation Approach. Exploiting the frugal innovation approach aligns with the objectives of the transformation plan carried out in our company, aiming to achieve a good level of cost savings and competitiveness while improving the production process. This vision is compatible with the Moroccan government's development plan for the industrial sector. Achieving good results through the application of the frugal innovation approach in the industrial sector, and meeting some of our company's transformation plan targets, confirms the success this approach can have in other activities and in the Moroccan industrial area in general. Figure 7 describes the steps that guide the exploitation of frugal innovation in our work, starting from the strategy of the Moroccan government and our company to the results realized by the frugal concept.

3.6.6. Relevant Articles on Frugal Innovation and Industrial Acceleration Plan. The frugal innovation approach is wellknown in emerging markets, referring to the practice of developing cost-effective and resource-efficient solutions to address the unique challenges faced by these regions. It is a mindset that emphasizes simplicity, affordability, and accessibility, enabling the creation of products and services that cater to the needs of a diverse and often price-sensitive consumer base. Recently, the frugal innovation approach has become more recognized in Morocco, with more authors showing interest in studying this concept and its applicability in the country. This approach not only fosters economic resilience but also contributes to the country's sustainable development goals by addressing issues such as education, healthcare, and renewable energy in a manner that aligns with Morocco's specific socioeconomic context.

Since the launch of the Industrial Acceleration Plan by Morocco, the author treats this pertinent initiative as a potential means to develop the economy and enhance the competitiveness of Moroccan industries, attract foreign investment, and create employment opportunities. The plan focuses on key sectors such as automotive, aerospace, agroindustry, and textiles, leveraging the country's geographic proximity to major markets and its skilled workforce. By fostering innovation, upgrading infrastructure, and providing incentives for industrial growth, Morocco aims to position itself as a regional hub for manufacturing and export. Table 4 lists the relevant articles dealing with the two axes of the frugal innovation concept and the Industrial Acceleration Plan [25–29].

3.6.7. Presentation of Both the Current Concepts and New Concepts

(1) Current Concept Description. The old concept is a manual assembly line, which is a system for assembly where



FIGURE 7: Choosing the frugal innovation approach.

numerous workstations are connected to each other in an appropriate sequence of operations [30]. Each workstation comprises personnel, a table, necessary equipment, and tasks to be performed in accordance with the work instructions. In the case of manual lines, complete reliance is placed on the line operators, meaning that the productivity of the line and the quality of the product are closely tied to human intervention. Figure 8 clearly illustrates a manual production line in our field of application [31].

In our case, "Manual lines" refer to a manual process for cable processing. The cable undergoes preparation in a cutting machine by cutting it to the desired length, stripping it, and crimping the center contact. Following this, the insertion of the sleeve support and outer contact is carried out manually, and the braid bending and ferrule crimping are performed using brushing and press machines, respectively. To establish a manual line, the necessary elements are described in Figure 9, including operators, space, cycle time, and investment cost.

(2) New Concept Description. The developed concept is related to the assembly process, with the objective of automating the assembly process using a transfer system between different stations. The ultimate goal is to minimize the human factor as much as possible in order to enhance product quality and line productivity. The primary challenge in this concept lies in offering a frugal solution for each process to reduce costs and enhance product quality. Figure 10 illustrates the proposed concept as model 1, with the second design being based on the same frugal approach but with one alteration related to the shape of the machine, adapting it to different production flows.

The proposed concept, named "Smart Machine," is a highly flexible and cost-effective assembly cell that integrates assembly and control operations for cable production. The cable is prepared in a cutting machine, where it is cut to the desired length and subjected to stripping and crimping of the inner contact. To construct our proposed concept, we will describe in Figure 11 the necessary elements, which include operators, space, cycle time, and investment cost.

According to Figure 11, the new concept offers compelling cost optimization benefits, resulting in a 40% reduction in labor costs, a 41% reduction in space requirements, and a 39% reduction in cycle time. However, it is important to note that there is also a significant increase of more than 79% in investment costs. The results of this concept will be compared with other production processes in the following paragraphs to provide a comprehensive evaluation of manufacturing costs for several concepts with varying degrees of automation.

4. Developed Concept: Frugal Concept

4.1. Frugal Concept. Our project aims to develop the cable production process assembly system in a frugal manner. The choice is based on the fact that this concept generates more value within the production chain. The first part of the global process is the standard cutting machine, shown in gray on the diagrams. After the assembly process, the cable undergoes electrical testing, and finally, it is packed in cartons and placed on pallets at the last station.

The core of our work in building a frugal concept is based on several factors. Technically, the concept is constructed by benchmarking basic solutions from various projects within our company, including different machine stations. In addition, the second principle is to minimize the human factor in each process step as much as possible by employing a transfer system between machine stations. To achieve great synchronization between the proposed solutions and the transfer system, we have chosen automation level 3. This level also provides a high degree of integration with our

	Date	2023	2022	2021	2021	2022	2014	2012	2012	2020		2021	2023	2016	2022	2022	2023
trial Acceleration Plan.	Articles	La relation entre l'innovation frugale et le développement social (the relationship between frugal innovation and social development)	Frugal innovation: Recommendations for the generalization of the concept in the Moroccan industry	Frugal Innovation Approach to Technology Driven Entrepreneurship in Emerging Economies	Frugal innovation in a crisis: the digital fabrication maker response to COVID-19	Frugal innovation as a key to supply chain success: projection into the Moroccan context	L'innovation démystifiée: Innovez aujourd'hui grâce à l'innovation frugale	Frugal innovation: A global networks' perspective	Jugaad innovation: Think frugal, be flexible, generate breakthrough growth	Les déterminants de réussite du plan d'accélération industrielle au maroc- essai d'annroche cyhermétione	La transformation digitalo-intégratrice (TDI) vecteur de	compétitivité et de performance organisationnelle (COPO): application à l'industrie aéronautique au Maroc dans le cadre du plan d'accélération industriel 2.0 (PAI. 2.0)	Attractivité territoriale et développement industriel au Maroc: Quelle place pour les écosystèmes d'affaires?	Les clusters au Maroc: vers l'émergence d'une nouvelle politique industrielle territorial	Les facteurs de performance des Zones d'accélération industrielles au Maroc: Cas de la Tanger Automotive City	L'industrie de l'automobile au Maroc, réalités du présent et défis futurs	L'industrialisation du Maroc à l'ère de la mondialisation: De l'émergence à l'accélération industrielle, Quels résultats
elevant articles on frugal innovation and Indus	Authors	Khalid Boukhari and Jalila Ait Soudane	Bilal Karroumi and Abdelfettah Sedqui	Ilyass Mousaid, Ali Kaya, and Ali Benmoussa	Lucia Corsini, Valeria Dammicco, and James Moultrie	Bilal Karroumi and Abdelfettah Sedqui	Nabil El Hilali	Tiwari Rajnish and Cornelius Herstatt	Radjou Navi, Jaideep Prabhu, and Simone Ahuia	 Abdelwatt El aidouni and Mohamed A nonche		Mokhtari Bouchaib and Mohamed Ettaibi	Brahim Idbendriss My and Debbagh Bouchra.	Amine Rajae	Lahsen Zerraf and Khalid Rguibi	Jalila Charjaoui	Hajar Fathi
TABLE 4: R	Axes				Frugal innovation concept								Plan implemented by the Moroccan government: Industrial	Acceleration Plan			

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FIGURE 8: Manual assembly line composition: The manual line consists of workstations and a manual transfer system between the stations.



FIGURE 9: Characteristics of a manual line: These characteristics are defined by four key factors: workers, surface, cycle time, and investment value.



FIGURE 10: Model 1 new concept (semi-automatic) composition. The concept consists of workstations and an automatic transfer system between the stations.



FIGURE 11: New concept (semi-automatic) characteristics. The characteristics are defined by four items: workers, surface, cycle time, and investment value.

Manufacturing Execution System. The design of the machine, with all stations grouped together, is aimed at optimizing space utilization.

Strategically, we are proceeding with the construction of the frugal concept in collaboration with local suppliers, and for some of them, we have the support of their groups outside Morocco. The goal is to ensure that technical support, raw materials, and spare components are consistently available. The decision to work with local suppliers also aims to develop Moroccan skills and facilitate technology transfer from our suppliers to our employees. Both fundamental aspects of development generate significant benefits in terms of product quality, manufacturing costs, and employee skills improvement.

The frugal concept is presented in two models. The first one is depicted in Figure 10, which is a rotary machine with a rotative transfer system and no operator displacement. The second model is shown in Figure 12, featuring a linear machine with a conveyor as the transfer system. Transitioning from model 1 to model 2 aims to maximize space utilization and adaptability to various production flows. Both models are valid, with a higher likelihood of utilization for the second model.

4.2. Frugal Solutions Exploited for the Models. The frugal solutions employed in this frugal model are based on internal benchmarking of other series projects, the utilization of solutions from our suppliers that are already owned by our company (thus, the development cost is already covered in the context of other projects), and the use of solutions developed internally by our company. A brief description of each machine station is given:

- (1) Station 1: cable fixation using a simple gripper developed with a supplier.
- (2) Station 2: component insertion using a similar solution already existing in another project without incurring development costs.
- (3) Station 3: manipulation of the cable using a solution developed entirely by our company.
- (4) Station 4: processing of the cable using a solution already available in the market without development costs.
- (5) Station 5: processing of the cable using a similar solution already existing in another project without development costs.
- (6) Station 6: processing of the cable using a similar solution already existing in another project without development costs.

In addition, a simple solution was developed with a supplier for the last station dedicated to cable unloading. The solutions used are the same for models 1 and 2, with the difference being the arrangement of the stations, either in a circular or linear configuration. The simplicity of the solution helps our concept to be adaptable to different locations with minor modifications. 4.3. Frugal Concept Results. The ultimate goal of developing a frugal concept is to achieve significant optimization through the utilization of frugal solutions and to assess the efficiency of frugality in a high-level project. To subject our concept to a real evaluation, we have conducted a comparison with other existing production processes. This comparison is performed at the outset to guide the development of a new concept, influencing the choice between manual, semi-automatic, or fully automatic processes, as well as the level of automation ranging from 1 to 5. Subsequently, an update to the comparison is conducted to evaluate the actual results of the first frugal machine developed based on frugal solutions, considering various criteria.

The detailed evaluation based on these criteria is presented in Table 5.

The most significant result of the comparison in Figure 13 is the cost of manufacturability per piece, which is derived from the evaluation criteria. It offers a clear and relevant perspective on the benefits of the solution in question. With a cost reduction of less than 59.7% compared to the manual process, less than 56.3% compared to the existing semi-automatic process, and less than 36.8% compared to the fully automatic process, this clearly indicates the effectiveness of the developed concept and underscores its importance in the strategy of our plant as outlined in the transformation plan.

The stability of product characteristics provided by the frugal concept is justified by its ability to conform to various product parameters throughout the production process. The variations in parameter values and the results of the realized capabilities are presented in the graphs in Figures 14 and 15 for the two controlled parameters: the position of the inner contact and the crimping height, which the machine manages during production.

The performed capability tests yield favorable results in terms of the position and distribution values for both parameters, crimp height and the position of the inner contact. The distribution follows the normal law, and the achieved capabilities for crimp height are 3.17 for Cp and 2.66 for Cpk, while for the inner contact position, they are 2.12 for Cp and 2.01 for Cpk. These capabilities indicate the machine's stability during the crimping and cable insertion processes studied, which will positively impact the reduction of detected issues and customer claims.

Regarding product quality, our frugal design has had a significant impact by eliminating the human factor during cable processing at the stations and by employing a robust transfer system. These two elements ensure the stability of product characteristics and prevent the occurrence of common problems often found in manual lines, with the two main issues being crimp nonconformity and short circuit. The graphs in Figures 16 and 17 display the results of problems detected in the manual lines compared to the new frugal concept, clearly demonstrating an improvement in the new frugal concept.

In terms of improving performance, the frugal concept we have developed has enabled us to reduce the waste rate by 0.2% compared with the manual line process, as well as gaining 210K capacity per year. The frugal concept has also



FIGURE 12: Model 2 new concept (semi-automatic) composition: The linear concept consists of workstations and an automatic transfer system between the stations.

TABLE 5: Comparison of manufacturing costs for different concepts.

Items	Frugal concept	Manual process	Semi-automatic machine	Fully automatic machine
HC (N)	3	5	3	3
Cycle time (s)	18''	23″	28"	7"
OEE (%)	95%	96%	85%	70%
Scrap rate (%)	1.8%	2%	4%	6%
CAPEX (€)	76950	185700	109714	341635
HC cost (€/year)	13608	22680	13608	13608
Space cost (€)	597.6	1018.8	612	8640
Spare part cost (€)	16000	10000	24000	65000
Production capacity (part/year)	1173000	972000	709714,286	2980800
Total cost (€)	107156	219399	147934	428883
Cost/part (€/1000Pcs)	91	226	208	144



FIGURE 13: Process cost/part comparison. The study aims to calculate the manufacturing cost for each process.



FIGURE 14: The measured value distribution for both parameters: crimp height and position of inner contact.



FIGURE 15: Position and distribution for both parameters: crimp height and position of inner contact.



FIGURE 16: Evolution of detected issues in the old production process: The study concentrated on two primary issues and their influence on three factors: capacity, scrap rate, and justified customer claims.



FIGURE 17: Evolution of detected issues in the new proposed production process: The study addressed two main issues that were also observed in the old concept, examining their impact on three factors: capacity, scrap rate, and justified customer claims.

enabled us to minimise defects by tackling crimping and short-circuiting problems. This has led to a 72.7% reduction in justified customer complaints (JCC), thanks to the solutions exploited in the concept developed, compared with the previous process.

4.4. Exploration of Results. The achieved results in the frugal system developed in the automotive sector, in terms of technical frugal solutions of the system (processing, accessibility in each station), system performance (cost,

output, scrap rate), and quality (defect rate, customer claims, and capabilities), encourage the exploration of applying the frugal innovation mindset in other activities and sectors. The strength of frugal innovation lies in its enormous flexibility when applied. The approach is not a set of steps to be followed to achieve desired results; instead, it is based on six principles that help guide thinking depending on the nature of the application. For this reason, frugal innovation is a mindset of reflection with the overall aim of proposing economical, flexible, and cost-effective solutions in situations characterized by limited resources. The results obtained in our frugal system can be explored in similar applications with the same reasoning; in this sense, the automotive sector presents a vast number of application opportunities. For different fields of application, it is a matter of understanding the core of the approach to proceed to propose frugal solutions in any field. Thinking outside the box is not an issue or a constraint for the frugal innovation approach.

5. Conclusions and Perspectives

Globalization is placing increasing stress on markets and business patterns. On the one hand, this is due to significant changes in the quantity and variation of requirements, and on the other hand, it is a result of fierce competition among suppliers of products and services. This business model is projected on both a large scale and at the country level. In these challenging circumstances, projects and transformations are initiated at both the country and company levels to address expressed needs, adapt to development, and avoid imbalances in the current situation.

This work aims to align the vision of Morocco as an ambitious country in terms of development and improvement projects, particularly in the automotive sector, with our industrial companies operating in the same field and our research approach to frugal innovation. In our work, we have aligned the objectives of the industrial acceleration plans launched by Morocco, including the latest plan for 2021–2025, with the contributions of our frugal innovation approach to this plan. Subsequently, we have applied this approach concretely in the automotive industry in Morocco to demonstrate the efficiency of frugal innovation and its capacity to improve critical situations in the industrial context of Morocco. This, in turn, confirms the applicability of this approach to our country.

This research indicates that our strategy is well-suited to address the challenges presented by the Industrial Acceleration Plan, demonstrating the potential success of this approach after its adaptation to the scope. Furthermore, we have highlighted the significant success of frugal innovation in our company's transformation plan, particularly in the development of a frugal concept with frugal solutions. This concept has enabled us to achieve remarkable cost optimization and has shifted our perspective on production process improvements. Our frugal approach allows us to produce products at a cost of less than 59.7% compared to the manual process, less than 56.3% compared to the existing semi-automatic process, and less than 36.8% compared to the fully automatic process. It also ensures a high level of product quality, resulting in a 72.7% reduction in customer claims for the first installed machine with the new concept.

These results clearly demonstrate the effectiveness of the developed concept. As a result of our concept, and with four machines currently utilizing this approach, our factory is considering replicating the concept 12 times to replace the manual production line and support the fully automatic machines. In addition, this frugal assembly machine concept has become the cornerstone of the Smart Automation axis and has led to improvements in both upstream and downstream assembly processes.

Future studies could expand the scope of Morocco's industrial frugal innovation concept to encompass other supply chain activities, including procurement, delivery, and inventory management. Furthermore, there is potential for research to explore its applications in other fields, such as renewable energy, which continues to evolve and gain significance. Frugal innovation can serve as a mindset, not just an application approach.

Data Availability

The data used to support the findings of this study have not been made available because most of the data used in this work originate from company's database, including the calculation and data processing tools. Therefore, the company name and certain technical terms specific to company's database are redacted.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

We would like to express our heartfelt appreciation to everyone at our company who was involved in the publication of this study article. Finally, we want to convey our gratitude to our family and friends for their encouragement and support during the study process, without whom we could not have completed our research. The publication costs will be covered by the principal author.

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