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Letter from the Editors

From the continuing rise of populist rhetoric, deepening global concern on climate change, and the emergence of stronger feminist foreign policy, there are many policy challenges that Canada is facing today. Living in an information saturated culture, it is difficult to disentangle oneself and engage in critical dialogue.

This year we sought to understand Canada's current policy issues by opening up our call to not only policy graduate students, but also those within other specialties. We wanted to create a dialogue to better understand how these policy issues are affecting Canada and will affect our future.

We would like to take this opportunity to thank all of the authors who submitted papers, and the editors and faculty at the School of Policy Studies for their time and support in putting this journal together.

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Industry 4.0 and the Competitiveness of Canada's Manufacturing Sector: Implications for Policy

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Industry 4.0 dominates discussions about the future of manufacturing. To many, its represents a means by which to sustain the manufacturing footprints of higher cost, economically advanced jurisdictions. In Canada, many observers have expressed concern that its manufacturers are not confronting the challenges – and opportunities – that Industry 4.0 represents. They fear that late adoption of Industry 4.0 technologies will have a significant impact on manufacturers' long-term capacity to compete. Even so, there exist several attributes within the fabric of the Canadian manufacturing sector, its labour market and educational system that make Canada and its manufacturers well-positioned to accept and catalyze the benefits that Industry 4.0 represents. While this paper cautions against Industry 4.0 being considered the remedy for Canada's declining manufacturing competitiveness, it describes why adoption of Industry 4.0 principles and the need for firms to increase their capacity to integrate into others' value chains is increasingly necessary. As such, it suggests a structure and process for Canada and its policy makers going forward.

Introduction

The emergence of data manipulation and analysis has facilitated the introduction of numerous technologies, many of which have found application in the industrial sector [1]. Developments in the fields of internet of things (IoT), cloud computing and big data analytics and their introduction to the field of manufacturing has allowed firms to migrate the management of their products, processes and services beyond the borders of a single establishment. This has permitted those firms to integrate processes aspects associated with the management of manufacturing operations and logistics [2, 3].

The rise of IoT and the cloud has also supported the advancement of manufacturing techniques which would not have been possible otherwise [4]. Terms such as "Industry 4.0" and "Cloud-Based Design and Manufacturing" have emerged, revolutionizing manufacturing paradigms [4,5]. Concepts and tools associated with Industry 4.0 support the introduction of interconnected

machines, sensors, assembly lines, computers and shipments and in so doing, enable broader, more visible and immediate control over operations [6].

Since the introduction of the concepts associated with Industry 4.0 in 2011, several countries have rushed to support the digitization and interconnectivity of products and systems in their industrial sectors [7]. Germany and the United States have been most active in this regard [7]. For many, the 2016 World Economic Forum represented a form of "coming out party" for Industry 4.0 as it was the dominant theme of the gathering. While Canada's Prime Minister, Justin Trudeau used the meeting to emphasize Canada's capabilities in several technological areas associated with Industry 4.0, many expressed concern then (and subsequently) that Canada was making minimal progress [8 - 10]. For example, according to the Organization for Economic Co-operation and Development (OECD), Canadian industry has lagged many developed nations in the adoption of emerging technologies that contribute to the integration of Industry 4.0 systems [11, 12]. Moreover, a survey conducted by the Business Development Bank of Canada (BDC) highlighted that almost 60% of Canadian manufacturers had not yet implemented technologies relevant to Industry 4.0 [12].
At its core, Industry 4.0 represents the integration of a set of constantly interconnected cyber-physical systems across a single network, [4] bringing customers, suppliers and manufacturers under a single umbrella. It facilitates customized mass production as well as reduced human intervention [4, 5]. The most significant aspect of Industry 4.0 is the potential it represents to integrate a firm's aggregate value chain – i.e. extending knowledge and visibility of a firm's or establishment's actions beyond the boundaries of that firm or establishment [6]. Effecting such a change requires all value chain members to be capable of communicating and exchanging data and information over a coherent and unified protocol [13].

For most firms, particularly those in the Small or Medium Enterprise (SME) category, developing such capabilities is beyond their remit. In the absence of supportive measures, efforts by such firms to integrate industrial ecosystems to global standards may prove fruitless, a turn of events that would cause an Industry 4.0-enabled ecosystem to be accessible to only the largest, most well-capitalized firms. This would effectively eliminate many firms – primarily SMEs – from large firms' ecosystem. Thus, Canada and its firms must increase their adoption of Industry 4.0 tools –

if not because of the firm level benefits Industry 4.0 provides, but because supply chains will increasingly demand that firms with whom they do business have the requisite capabilities. Thus, Canadian federal and provincial governments, in conjunction with Canadian manufacturing sector(s), must be involved: introducing and implementing a strategy to propel the adoption of Industry 4.0 technologies.

This paper will provide the basis for a guide for integrating Industry 4.0. To support that, a literature review is conducted, its purpose being to isolate technologies and tools considered essential to Industry 4.0. After that, an assessment is conducted of the preparedness of Canada to host and advance the incumbent technology. Doing so provides a basis for development of a policy path going forward; one that will position Canada to take systematic steps towards the advancements Justin Trudeau articulated at the World Economic Forum in 2016.

The Structure and Fundamentals of Industry 4.0

Industry 4.0 is the term given to self-automated cyber-physical systems connecting diverse elements of the manufacturing and management process [5]. It functions through real-time networking between technologies over the Internet of Things (IoT). The "Things" refers to the cyber-physical systems and technologies that are linked together by the internet, supporting decision making in real-time. The effect is improved visibility and efficiency of the overall supply chain [4]. By breaking down the technologies and tools associated with Industry 4.0 a basis is provided for capturing its complex nature.

a. Elements of Industry 4.0

Literature shows that Industry 4.0 is often associated with a range of contributing digital technologies, tools and methods which alter manufacturing value chains. These tools and technologies include those that enable product design, product customization, supply chain management, production, delivery and customer feedback [5,6,14,15]. However, in assessing core Industry 4.0 tools, it is necessary to distinguish between technologies fundamental to Industry 4.0 from those elements which merely contribute to other aspects of manufacturing. Failure to distinguish between the two types causes individuals and firms to delay progress in terms of

planning and implementing Industry 4.0. Through a review of literature, we identify nine commonly presented technologies labelled as fundamental to Industry 4.0 [5,6,14,15].

1. Cloud Computing
2. Big Data and Analytics
3. Internet of Things
4. Additive Manufacturing
5. Augmented Reality
6. Cyber Security
7. Smart Sensors
8. Autonomous Robotics
9. Simulation

Most studies and reports conducted on the structure and elements of Industry 4.0, present these technologies and tools as an Industry 4.0 package without highlighting the significance of specific elements [5,6,14,15]. In the aggregate, one could anticipate that the prospect of developing and implementing a comprehensive, integrated strategy involving all nine would be overwhelming. By contrast, the provision of a supporting guide or framework for an incremental and gradual transformation would be more manageable, allowing firms to plan investments over a prolonged timeframe.

b. Industry 4.0's Fundamental Elements

The pivotal technologies and tools of Industry 4.0 are those that support the underlying architecture [16]. Without them, any subsequent overhaul of a firm's manufacturing system(s) cannot occur. This section describes those aspects.

Bagheri et al. (2015) present a five-level architecture for Industry 4.0 systems, describing the major operational steps involved [16]. They are:

a. Smart Connection: Represents the collection of data from modules and instruments such as sensors, controllers, machines and enterprise management systems
b. Data-to-information conversion: Here data is gathered, organized and converted into usable material and information

c. Cyber: This step captures the exchange of information that occurs among interconnected components over the manufacturing network
d. Cognition: Represents the process of knowledge-generation and decision-making as a result of the information acquired
e. Configuration: This step translates the cyber-decision of cognition level into a physical feedback through intelligent and self-adaptive machines and controlled systems

c. Analysis

Based on Bagheri's model, several elements can be identified as primary technologies and tools. Critically, the Bagheri model strips Industry 4.0 down to its core elements. The collection of data at the first stage is accomplished the presence of digital sensors, machines, programmable logic devices and controllers along the assembly line. Also, management and logistics data, along with data from suppliers and consumers is collected. According to Bagheri et. al, the ever-growing network of machines and sensors, and the constant generation of large sets of data has resulted in

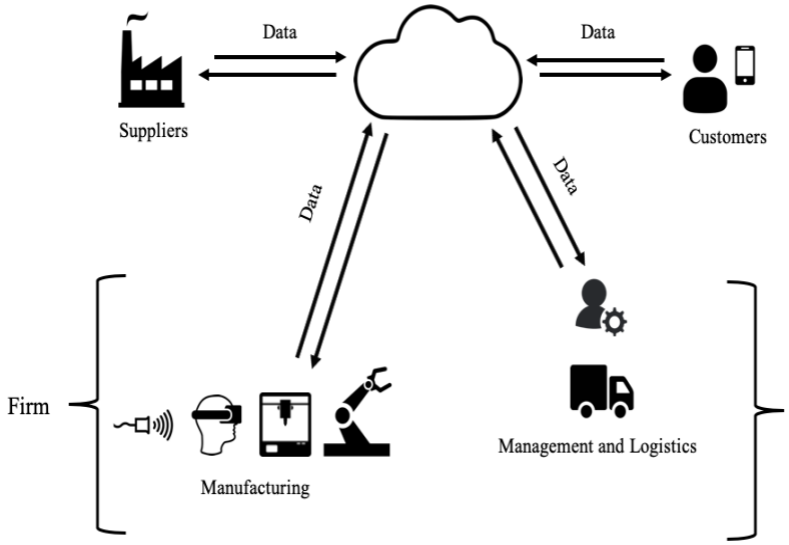

Fig. 1 - Reorganized structure of Industry 4.0

While the Cloud can act as the central bridge of the Industry 4.0 system – where data is stored, analyzed and exchanged across the network of devices – it is also important to acknowledge the role of data in the overall process. From the first level of data generation and collection using sensors, controllers and machines, to the analysis and intelligent decision-making process, data is

constantly generated, analyzed and exchanged over interconnected systems. This makes the presence of data and information essential to the system's functionality.

Industry 4.0 expands the spectrum of data generation and utilization in an attempt to enhance the process, extending its role beyond the assembly line. Suppliers and customers are also direct contributors to the network. For this reason, we identify data as the fundamental element for the functionality and structure of Industry 4.0. Therefore, capabilities for understanding and managing "Big Data and Analytics" at firms and companies is essential for the integration and the operation of Industry 4.0 systems.

Though other elements of Industry 4.0 such as additive manufacturing and augmented reality may convey the advancement and modernity of new manufacturing, they are not essential to Industry 4.0. The tendency to associate ancillary elements, which do not enter or contribute at all levels of the functionality of Industry 4.0 system, may leave organizations – especially SMEs – with the impression that Industry 4.0 is beyond their reach. For this reason, the storage and management of data is the core of Industry 4.0. The tendency to add "Advanced Manufacturing" tools to the fundamental elements of Industry 4.0 undermines Industry 4.0 progress at the firm and sector level.

Industry 4.0: The Canadian Case

At the World Economic Forum of 2016, Canadian Prime Minister Justin Trudeau presented characteristics of the Canadian industry that made it uniquely capable of hosting Industry 4.0 [7, 10]. According to the Prime Minister, Canada's economy, its infrastructure, population, education system and organization of governance combined to provide attributes facilitative of Industry 4.0 [7]. However, according to several observers, Canada does not possess an integrated and comprehensive national strategy to assist the Canadian manufacturing sector in transitioning its industrial network to the kind of new manufacturing systems and procedures that Industry 4.0 represents [11]. By contrast, seven of the top 10 global economies (by Gross Domestic Product), have developed national strategies to accelerate industrial transformation [26 - 28]. Figure 2 lists those jurisdictions and the budgets they have assigned to Industry 4.0 endeavours. For example,

Germany, in 2011 earmarked €400 million to its "Industrie 4.0" program. By 2015, the UK, Italy, the US, Japan and China had also enacted strategies [29 - 32]. As for Canada, an overview of its support programs and funds shows that the presence of the Industry 4.0 concept in its industrial programs has been minimal. Thus, unlike its major competitors, Canada has not yet set a national strategy to fast track industrial transformation.

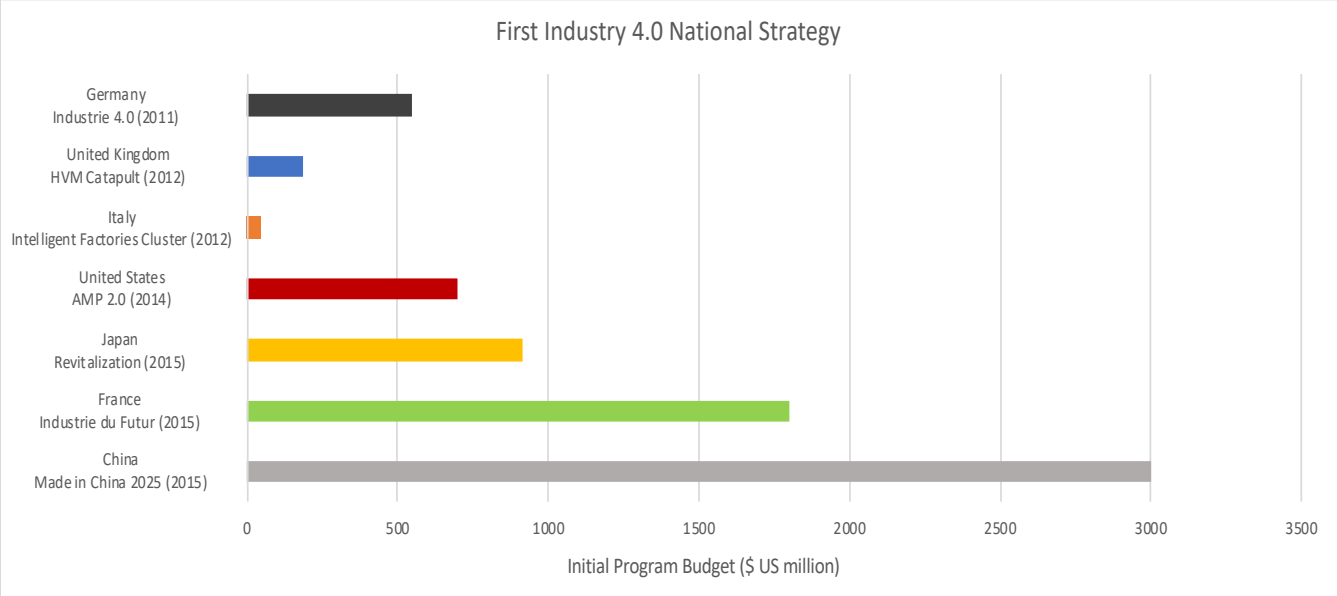

Fig. 2 - First Industry 4.0 Governmental Program by Country

A review of the Canadian and US manufacturing sectors shows that based on the Gross Domestic Product (GDP) of the manufacturing sector, the United States spends more than twice as much as Canada on information, communication and technology (ICT) equipment and applications (Table 1) [33, 34].

	Manufacturing Sector		
Country	GDP Manufacturing (USD billion)	ICT Investment (USD billion)	ICT Investment as a Share of Manufacturing GDP (Percentage)
United States of America	2,017	55	2.72%
Canada	178	2.22	1.24%

Table 1. ICT Investment in the Manufacturing Sector in US and Canada

The absence of industrial programs and funds aimed at accelerating the adoption of Industry 4.0 technologies and systems, combined with low ICT investment in Canada's manufacturing sector, provides evidence that Canada has insufficiencies related to Industry 4.0 readiness and implementation. Despite its direct shortcomings, Canada does possess several attributes facilitative of Industry 4.0. The sections that follow document several of those features.

a. Canadian Educational System

In 2016, the OECD ranked Canada at the top of its member countries (educational index) with 54% of the population being a university or college graduate [35]. Almost 20% of Canadian academic institutions, and 55% of the 20 largest Canadian universities offer a data-related program structured to engage students in gaining expertise in the management of data [36]. Additionally, there exists several tools and programs to engage university and college students with Canadian industry. These programs include Mitacs Canada and the Co-operative Education program [37, 38].

b. Government of Canada Initiatives

In the federal budget of 2017, Canada allocated $950 million over five years towards an "Innovation Superclusters Initiative," [39] aiming to increase collaboration among institutional and industrial actors in the areas of research, innovation, and job creation [39]. Among the five superclusters, we identify two which have application to the support and promotion of Industry 4.0. The Digital Technology Supercluster in British Columbia brings together more than 250 Canadian and international industrial and academic partners to tackle issues and challenges related to service delivery in the natural resources, health and manufacturing sectors, through the incorporation of big data applications, cloud computing and machine learning [40]. Meanwhile, the Advanced Manufacturing Supercluster in Ontario concentrates on manufacturing-oriented technologies such as 3-D printing, advanced and autonomous robotics, machine learning, IoT and cybersecurity [41].

The superclusters are currently at the stage of setup. As such, it is too early to draw conclusions about their ultimate relevance towards the advancement of Industry 4.0. However, both

superclusters, carry potential for creating opportunities. Even though the language associated with their establishment contains minimal mention of Industry 4.0, their technology focus areas are pivotal to engaging the manufacturing sector in the Industry 4.0 paradigm. The extent to which these clusters are able to collaborate on projects will also support advancements in Industry 4.0 and generate additional opportunities. (Note: Table 2. summarizes the focus areas of each of the two superclusters along with the technologies and tools associated with Industry 4.0.)

Technology Focus		Structural Elements
Digital Technology Supercluster	Advanced Manufacturing Supercluster	Industry 4.0
- Virtual, Mixed and Augmented Reality ★ - Data Collection and Analytics ★ - Quantum Computing	- Internet of Things ★ - Machine Learning - Cybersecurity ★ - Additive manufacturing ★	- Cloud Computing - Big Data Analytics - Internet of Things - Additive Manufacturing - Augmented Reality - Cyber Security - Smart Sensors - Autonomous Robotics - Simulation

Table 2. Technology Focus of the Two Superclusters and the Structural Elements of Industry 4.0

c. Governmental Policy

Beyond the superclusters, the Canadian federal and provincial governments offer subsidies and loans aimed at development of Canada's industrial sector [42]. For example, the National Research Council of Canada (NRC) promotes research in areas of data science and analytics, machine learning, deep learning and artificial intelligence [43]. In January 2018, NRC's Industrial Research Assistance Program (IRAP) announced the "Canada-Germany Industry 4.0 Partnering Mission",

which later developed to a joint Canada-Germany call for R&D projects in Industry 4.0 technologies involving SMEs and academic and research partners in Canada and Germany [44, 45]. Other programs such as the Automotive Innovation Fund (AIF) and Canada's Small Business Financing Program also offer financial support to Canadian companies to invest in new machinery and equipment [46, 47]. While there are no explicit requirements stipulating what technologies or tools should be acquired [46, 47], Industry 4.0-oriented projects are eligible.

d. Non-Governmental and Private Initiatives

Several innovation hubs and incubators have surfaced to accelerate advancements directly and indirectly related to Industry 4.0. Among these is Catalyst 137, an innovation space for manufacturing technologies and the IoT in the Region of Waterloo, strategically located to attract contributions of major companies such as Google and Toyota as well as academic institutions like the University of Waterloo [48]. The hub is not focused exclusively on Industry 4.0, but collaboration involving technologies and tools associated with Industry 4.0 are possible.

Another hub is the MARs Discovery District, a non-profit corporation in Toronto aimed at promoting partnerships among more than 120 Canadian and international public and private organizations [49]. Like Catalyst 137, MARs do not directly relate to manufacturing technologies or Industry 4.0, but data-related technologies and methods, along with AI and machine learning are integrated in the research and operations of more than 25 percent of its members [50]. The hub has also been successful in supporting more than 50 ventures in the field of data science and analytics [51]. Other Canadian hubs and innovation centres include McMaster University's Innovation Park in Hamilton, Ontario and the University of Calgary's "Innovate Calgary", in Calgary, Alberta [52, 53].

e. Technology Companies and the Canadian Job Market

Canada is a hub for technological advancement, recently developing and major international firms [54]. Several companies have recently announced plans to establish or expand their presence [54]. In 2018 for example, Microsoft, Uber, Alphabet and Samsung announced investments in Toronto [54- 57]. Montreal's Artificial Intelligence and Deep Learning Hub, along with the recent

announcement of the Quebec-based Scale AI supercluster, have encouraged Microsoft, Google and QuantumBlack (the data analytics subsidiary of McKinsey & Co.) to establish or increase their AI and big data R&D activities there [58, 59].

In 2017, Toronto was the fastest growing North American tech job market, adding approximately 29,000 tech jobs, 3.5 times more than the second ranked city, Seattle [54, 60]. Ottawa ranked first on the list of the highest North American tech-labour concentrated cities, with tech jobs constituting 11.2 percent of its job market. The share of tech jobs in the Canadian job market is almost 1.5 times higher than the share of tech jobs in the U.S. (Table 3).

Country	Labour Market (Full-time employees)	Tech Jobs	Percentage of Tech Jobs to Labour Market
United States of America	127 million	5 million	3.9%
Canada	14.8 million	0.83 million	5.6%

Table 3. Share of U.S. and Canadian Tech Jobs

Policy Discussion

The 1970s were associated with digitalization and mechanization of industrial production [5, 61]. Since then, sensors, controllers and machines have become an integral part of manufacturing systems, providing real-time data and continuous monitoring and feedback [62]. However, the data generated from earlier-designed systems has been limited to their placement in discrete, isolated machines or production lines [16, 62]. Industry 4.0 is distinguished from that by virtue of the fact that data is extracted, analyzed and distributed across a network. Since data plays a fundamental role in the structure of Industry 4.0, it is the essential and primary step for manufacturing companies (and policy makers) to consider as they build an Industry 4.0 compatible infrastructure.

Based on the data and trends described above, Canada possesses resources and skills to support an Industry 4.0 transformation. However, research undertaken in the course of this project has suggested that Canadian industrial policy reflective of the nature and scale of Industry 4.0 lacks structure and focus. With no national strategy or consolidated support programs in place to

promote digitization and interconnectivity, Canadian companies, especially SMEs, will be challenged. The globally accelerating adoption of Industry 4.0 systems places Canadian firms in general and SMEs in particular in a vulnerable position; one where a risk exists of them being excluded from the emerging ecosystem.

This paper has sought to underscore the fact that firms will increasingly be compelled to integrate key aspects of Industry 4.0, not necessarily because doing so will make them more productive or because Industry 4.0 tools will transform the quality of their outputs (although it may). Rather, Industry 4.0 will increasingly reach the status of "table stakes." Firms wishing to be part of other firms' global value chains will be required to possess Industry 4.0 capabilities. Thus, it can be anticipated that the requirement for Industry 4.0 capability will accelerate.

Despite the resources, initiatives, skills and expertise present in the Canadian market, Canadian firms in general and SMEs in particular, will struggle to affect the transition necessary. Consistent with other economically advanced jurisdictions, Canada requires an overarching strategy to coordinate and synchronize its efforts with respect to Industry 4.0. This is important for all firms, but for SMEs, which by their nature lack access to the range of skills and knowledge necessary to effect the transition, this is particularly important. We believe that developing a national strategy for tackling this issue can be manageable and economically viable. It must coordinate and harness existing resources and assets while following an agenda of gradual integration of ancillary technologies and tools. Moreover, because Canada's national and subnational governments already offer a set of support programs and funds aimed at building the capacity of the manufacturing sector, a basis for a tighter Industry 4.0 strategy exists.

Conclusion

For firms, the implementation of Industry 4.0 can represent a complex, imposing undertaking. As currently represented, Industry 4.0 consists of a collection of disparate technologies and concepts that, in the aggregate, can overwhelm firms, both large and small. This paper has demonstrated that a more strategic and systematic approach – one that is incremental and supported by a

broader government strategy or approach -- can mitigate the challenges and risks for individual firms.

This paper has argued that the starting point for both firms seeking to implement Industry 4.0 and governments seeking to support and guide firms as they do so, is data science and analytics. Other tools – e.g. additive printing, augmented reality or autonomous robots – while useful, do not represent core, requisite aspects of Industry 4.0 and therefore should be isolated from an consolidated Industry 4.0 strategy. The transition towards a revived manufacturing system is more likely if key stakeholders, including national and subnational bodies and institutions are aligned and centred on core elements.

This paper has confirmed that Canada contains many of the necessary attributes associated with a successful transition to Industry 4.0. It has a well-educated workforce, well-capitalized firms, and capabilities in technologies facilitative of its key aspects. However, it is also challenged in that does not yet offer a comprehensive and integrated Industry 4.0 strategy, nor does it appear that one is imminent. Meanwhile, its major competitors among highly advanced, economically developed nations have implemented strategies and programs that are well-ingrained. Canada must move rapidly, otherwise it risks losing the opportunity to leverage the benefits of the investments it already possesses in aspects foundational to Industry 4.0 success.

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