Appendix A

HALTON REGION DIGITAL ACCESS STRATEGY

Prepared for

Prepared By

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Executive Summary

This report, commissioned by the Halton Region, and prepared by Nordicity Group Limited ("Nordicity")[1], presents Digital Access Strategy for the Region – referred to as ***Halton Region Digital Access Strategy (HDAS)***. The main objectives of the report include a) assessment of the Region's digital infrastructure readiness, b) identification of options for next generation broadband connectivity in the Region (5G and Fibre) and its associated socio-economic benefits, and c) recommended digital access implementation action plan.

The Region's economy exhibited a growth of 1.4% per year, as its GDP increased from $24.03 billion (2016) to $25.40 billion (2020). In the emerging digital world digital transformation of the economy will be crucial for its long-term sustainable growth. The digital sector creates high value jobs for knowledge workers. Given the share of digital sector has remained constant around 9% its GDP, it presents an opportunity to further grow the Region's economy through digital transformation.

The analysis presented in this study demonstrates that the adoption of 5G technologies will significantly increase the digital sector share in the Region's GDP which will double it's the current growth rate. 5G technology will have a transformative effect on employment, productivity, and GDP in the different sectors of the Region's economy. The adoption of 5G applications (***Artificial Intelligence***, ***Cloud Computing***, ***Internet of Things***) will transform key sectors of the national as well as regional economies and improve the quality of life for its '*digital citizens*'.

However, the adoption of these 5G applications require the deployment of 5G wireless communication networks as the existing 3G and 4G networks will not be able to provide the comprehensive key performance characteristics such as "adaptive architecture", bandwidth speed and capacity necessary for the massive number of connected devices in Internet of Things (IoT) ecosystem. The 5G networks are required for *mission-critical*, *high-bandwidth*, *low-latency* applications such as *autonomous vehicles*, *patient-centric health*, *enhanced-reality*, etc.

5G networks will enable connected societies – ***"smart cities"***, ***"smart businesses"***, and ***"smart industries"***, that will transform society and offer long-term sustainable socio-economic wellbeing.

While 4G network technology continue to support the evolution of the Gigabit Economy, it is believed that 4G will soon reach its limits in terms of its ability to support the exponential growth in demand for bandwidth speed and capacity requirements in wireless networks. For example, 4G networks will be inadequate for the next set of high-bandwidth, low-latency video applications such as remote surgeries in the health sector, guided vehicles, robotic, drone and 3D printing in manufacturing processes, autonomous/connected vehicles etc.

To fully realise the socio-economic benefits of the 5G technologies as detailed in this study, the Region will require an integrated approach regarding the broadband network capability deployed by the ISPs. For example, Ciena (a major US based telecom technology firm), in its 2017 whitepaper noted ***"5G is not just about the Radio Access Network (RAN). Next-generation wireless is going to need a lot of help from wireline technologies to deliver on its promises***.

In this sense, the availability of next-generation high speed broadband connectivity (both wireline and wireless) in the Region will be critical to enable the economic benefits of 5G technologies. Accordingly, it has been recognized by policy makers such as CRTC that a modern broadband infrastructure is a critical enabler for widespread availability of high-speed internet services and correspondingly, digitally enabled citizenry, as well as innovation and growth in all sectors of the economy.

It is worth noting, that as with previous communications technology windows, it is likely that 5G networks in Canada will also be deployed first in large metropolitan areas with progressive deployments

along the transportation corridors and smaller centres. Therefore, it is critical for the Region to implement an effective digital access strategy to ensure it is not left behind from its peers in the adoption of 5G enabled technologies, which will be instrumental for sustainable growth in the emerging digital economies.

Given the exponential growth in broadband usage, it is likely that in the near future the demand for internet speeds will be significantly higher than the CRTC's current target speed of 50/10 Mbps. The CRTC reports also indicate that there has been an exponential growth in the broadband usage in Canada. Therefore, it is reasonable to believe that demand for internet speeds will reach up to 1 Gbps in the Region in the medium term. We also believe that businesses, industry, and MUSH (Municipalities, Universities, Schools, and Hospitals) institutions are likely to require 1 Gbps or higher speed internet services. Similarly, residential, including self-employed and work-from-home, demand for the internet speed is also expected to increase exponentially, ranging between 100 Mbps and 1 Gbps

The full realization of the economic benefits of 5G technologies will depend on the availability of a fully integrated wireless and wireline broadband capability across the Region, using next generation network technologies i.e., 5G (wireless) network supported by FTTH/P (wireline) network. This means the FTTH/P network capability across the Region will be a key enabler of the delivery of reliable 5G services and full realisation of the associated economic benefits. However, based on our assessment a significant gap exists in most parts of the Region in terms of broadband capability in meeting the emerging demands for reliable and scalable highspeed services in a digital (1Gig+) economy

As per ISED data the households in the Region are mostly covered with 50/10 Mbps. It is worth noting that availability of reliable internet speed depends on the technology (e.g., copper-based DSL, Fibre, Wireless etc.) used to deliver services. Since, the majority of those households are not served with Fibre-to-home technology ISED broadband coverage data, in our view, appears to present a very optimistic view. According to our estimates about less than a one third (30.6%) of the households in the Region may have access to reliable internet services potentially meeting the CRTC target speed of 50/10 Mbps or more. This means a significant gap exists in most parts of the Region in terms of broadband capability in meeting the emerging demands for reliable and scalable highspeed services in a digital (1Gig+) economy.

Therefore, there is need for deployment of a unified broadband network by the ISPs in the Region using future proof FTTH/P technology. A unified broadband network means an integrated fibre based wireline network delivering broadband connectivity services across the Region, using uniform standards in terms of internet speed capability and quality of service. We believe a unified FTTH/P network capability across the Region will be critical to the full realization of the economic benefits of 5G technologies as presented in this study.

According to our assessment, the ISPs would require about $362.8 million investment to deploy FTTH/P network in the unserved/underserved areas of the Region. This investment 82% of the total $439.5 million to deploy a future proof FTTH/P network across the entire Region. This means it will make more sense for the ISPs to deploy a unified future proof FTTH/P network in the Region, with an additional investment of $76.7 million. However, the $439.5 million represents our estimate of total the investment required for the deployment of FTTH/P network in the Region - *excludes the value of any existing FTTH/P network deployed in the Region and the impact of any potential Federal and Provincial funding for the Region*.

In our view a unified FTTH/P network would future proof the Region's broadband infrastructure capability in terms of meeting the exponentially increasing demand for internet speed and broadband usage in emerging digital world. The unified broadband service would be scalable up to and beyond 1

Gbps as required and ensure service reliability and redundancy. We also believe there is need for an open access regime to prevent deployment of duplicate networks by different ISPs. An open access regime would encourage competing service providers to offer a range of innovative and affordable services to different subscribers' groups across the Region.

Organization of report

After a brief introduction to this study in Section 1, we provide a detailed understanding of 5G technology in terms of its definition, evolution and capabilities as well as presentation of evidence to confirm that it has no adverse health impacts.

In Section 3 we demonstrate the need for digital access strategy for the Region, followed by assessment of digital infrastructure readiness in Section 4, and analysis of options to implement next generation broadband connectivity in the Region in Section 5. Section 6 the details modelling framework used to estimate the socio-economic benefits of 5G technologies, which are presented in Section 7. In Section 8 we present our recommended digital access implementation plan, followed by our conclusion in Section 9.

1. Introduction

There is extensive empirical evidence in the economic literature that shows the presence of modern digital infrastructure is an important driver for sustainable economic growth[2]. The advancements in digital technologies have played an instrumental role in accelerating economic and productivity growth across all sectors of the economy. That is, the presence of modern digital infrastructure is a key enabler of innovation and modernization for industries like *agriculture*, *mining*, *manufacturing*, *trade*, *services*, among others. Widespread use of digital technologies has led to job creation in existing industries as well as the emergence of new services and industries. A modern digital infrastructure also facilitates economic integration, improves living standards, and effectively assists *health*, *education*, and *businesses* in all sectors.

Therefore, the presence of a modern digital infrastructure enabled by the next-generation broadband capabilities is becoming increasingly important for long-term economic development and sustainable growth. The building blocks of the next-generation digital infrastructure are illustrated in Figure 1 below.

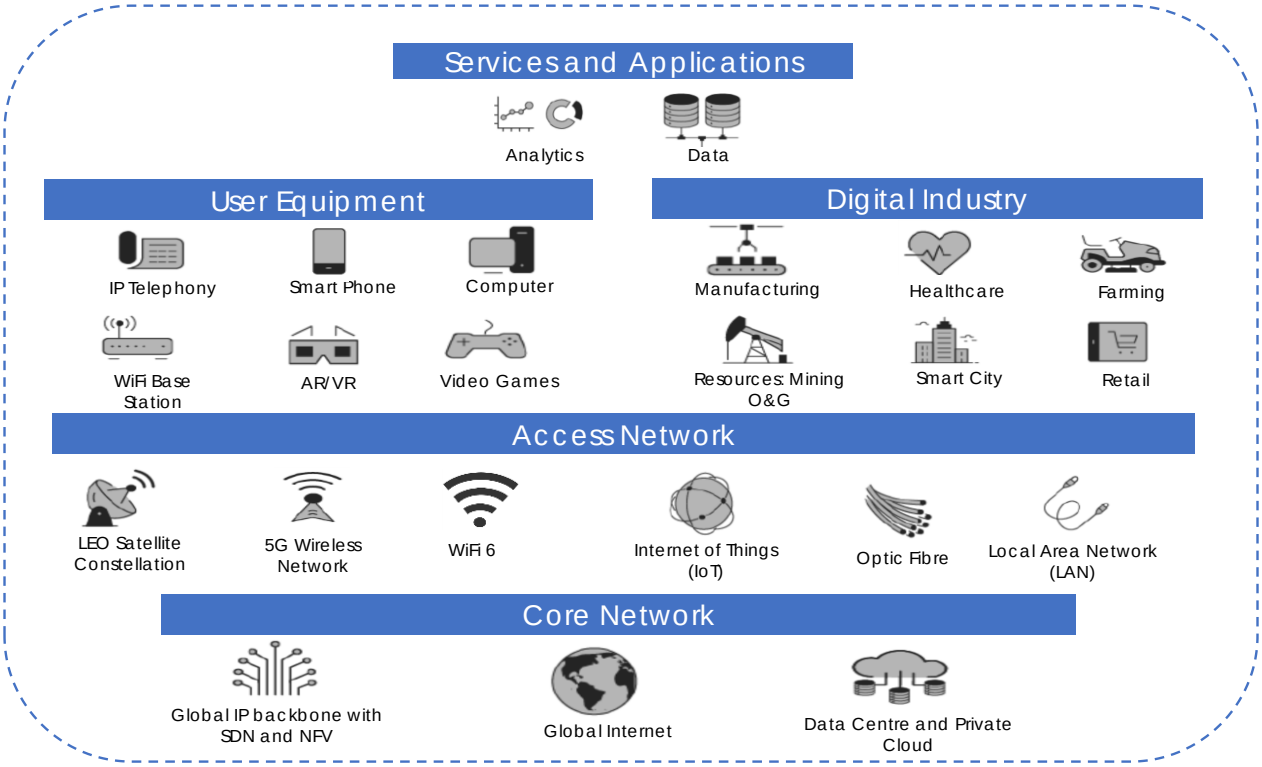


Figure 1: Digital Infrastructure Building Blocks

As shown in the above figure, the quality and capacity of both *wireline* and *wireless* broadband networks, encompassing "Core Network", and "Access Network" play a foundational role in the development of a modern digital infrastructure capability. Next-generation broadband capability means deployment of a future-proof[3] fully integrated fibre-based wireline and 5G wireless networks. That is, a high-quality fibre-based access network capability will be critical to fully realize the economic benefits of 5G enabled services. As 5G networks are enabled, the demand for broadband connectivity (i.e., internet speed requirement and data usage per capita) in urban, suburban, as well as rural areas will exponentially increase. This means the network operators will need high-performing 5G transport

network capabilities that are easy to scale - ***"5G is not just about the Radio Access Network (RAN). Next-generation wireless is going to need a lot of help from wireline technologies to deliver on its promises.[4]"***

The adoption of 5G technologies will transform key sectors of the national as well as regional economies and improve the quality of life for its '*digital citizens*'. The rollout of 5G technologies require the deployment of 5G wireless communication networks as the existing 3G and 4G networks will not be able to provide the comprehensive key performance characteristics such as "adaptive architecture", bandwidth speed and capacity necessary for the massive number of connected devices in Internet of Things (IoT) ecosystem. The 5G networks are required for *mission-critical*, *high-bandwidth*, *low-latency* applications such as *autonomous vehicles*, *patient-centric health*, *enhanced-reality*, etc.

2. Understanding 5G Technology

2.1 Defining a 5G Network

5G networks provide a significantly higher capacity than current 4G networks based on higher data rates, better spectral efficiency, coverage, and lower latency. 5G networks enable a much higher density of mobile users, massive IoT, and machine communications, amongst other benefits. In sum, 5G wireless broadband network technologies are **"***a set of technologies connecting people-to-people and people-to-information to a unified connectivity fabric connecting people to everything"*[5] .

5G networks operate primarily on mid-band spectrum (3.5GHz and above) but also require multiple lower spectrum bands (currently used by 3G and 4G networks) through dynamic network optimization technology.

2.2 Wireless Networks – Evolution and Capabilities

Since the inception of the first generation (1G) analog cellular networks in the 1980s and through the subsequent evolution of 2G through 4G digital networks, the telecoms industry has seen rapid growth in the penetration and adoption of mobile telecom services in Canada and the USA as well as globally [6].

The exponential growth in the demand for mobile services led to major advancements in wireless network technologies approximately every 10 years, resulting in the emergence of groundbreaking 4G networks in 2010.

As shown in Table 1 below - *summarizing the key characteristics and features of wireless network generations deployed*, the focus of previous advancements in wireless technologies (1G to 4G) was to enable subscribers to add data services to voice in wireless service offerings and subsequently improve data speeds and usage.

The rollout of 4G/LTE networks has spurred exponential growth in wireless broadband usage and correspondingly, opportunities for new technologies that are affecting all parts of our society – *Internet of Things (IoT)*, *Autonomous Vehicles (AV)*, *eHealth*, *mobile banking*.

The commercialization of these technologies will transform our existing socio-economic system into, what is referred to as the "***Gigabit Economy***"[7].

Table 1: Basic Comparison of Different Generations of Wireless Network Technologies

Basic comparison among mobile system generations*					
Feature	1G	2G	3G	4G	5G
Deployment	1980	1990	2001	2010	2020+
Frequency band	800 MHz	900 MHz	2,100 MHz	2,600 MHz	3–90 GHz
Speed	2 Kbps	64 Kbps	2 Mbps	Less than 1 Gbps	1 Gbps and more
Latency[1]	In seconds	500-1000 ms[1]	200 ms[1]	100 ms[1] and less	1 ms[1] and less
Technology	Analogue cellular	Digital cellular	– HSPA – UMTS – 1xRTT/EVDO	– LTE Advanced – Wi-Fi	– Multi-radio access technology – Wi-Fi – Wi-Gig
Services	Voice	– Digital voice – SMS – Packet (General Packet Radio Service), – Low-rate data	– Higher quality audio and video calls – mobile broadband	– High data rate – Wearable devices	– Very high data rate[1] to fulfill extreme user demands – Device-to-device, – Machine-to-machine, – Internet of Things
* N. Al-Falahy and O. Y. Alani, "Technologies for 5G Networks: Challenges and Opportunities," in IT Professional, vol. 19, no. 1, pp. 12-20, Jan.-Feb. 2017					

To realize the full benefits of the *Gigabit Economy*, 5G wireless networks are required as only these networks can provide the requisite key features:

- higher data rates (> 1 Gbps),
- improved spectral efficiency,
- lower delays (latency), and
- greater reliability (performance).

While 4G network technology continue to support the evolution of the Gigabit Economy, it is believed that 4G will soon reach its limits in terms of its ability to support the exponential growth in demand for bandwidth speed and capacity requirements in wireless networks. For example, the initial service sets for the *Internet of Things* being deployed in 4G networks as narrow band applications (NB-IoT), are inadequate for the next set of high-bandwidth, low-latency video applications such as remote surgeries in the health sector, guided vehicles, robotic, drone and 3D printing in manufacturing processes, autonomous/connected vehicles etc.

5G communications networks can enable the capacity and efficiency required to support the large-scale commercialization of new technologies in all sectors of the economy and in turn, generate benefits throughout our society. That is, *"As the demand for high-speed and low-latency applications increases dramatically, the 5G system should have the technology and flexibility to meet those requirements and support multifold increases in network capacity and connectivity."*[8]

5G will deliver capacity and efficiency not currently possible with the existing wireless network technologies[9]

For example, 5G enabled networks can offer speeds of up to 1Gbps for tens of connections and tens of Mbps for tens of thousands of connections. Examples of key improvements in the operating characteristics of 5G over 4G networks include the following:

- Greatly enhanced mobile broadband data rates that enable ever faster flows of greater amounts of information.
- Ultra-low latency and reliability—which is suitable for mission-critical services (see Figure 10 below)
- Ability to scale significantly and efficiently to connect a massive number of sensors; and,

- Enhanced security, such as capabilities around biometric identification to help safeguard the integrity of information.

5G networks will enable connected societies – ***"smart cities"***, ***"smart businesses"***, and ***"smart industries"***, that will transform society and offer long-term sustainable socio-economic wellbeing.

2.3 5G Technology – Potential Health Impacts

Over the last 50 years, manufacturers and wireless service providers have steadily innovated over various 2G, 3G and 4G iterations to meet consumer demand for a vast range of services and improved quality and reliability. 5G[10] services - first launched in April 2019 for the consumer markets in South Korea and the US[11], offer significantly higher performance parameters (bandwidth speeds, extreme lower latency, reliability), as mentioned above.

5G networks comprise small (micro) cell antenna and cellular towers (macro cells) for data throughput and coverage respectively. The very high data flow traffic in urban and suburban (higher population density) areas, require a densification of the radio access network (RAN) via the installation of small cell antennas. These small cells use mid band spectrum characterized by higher bandwidth but lower coverage. Thus, service providers are in the process of installing radio antenna on the streetlights, rooftops and sides of buildings. While there are more small cell transmitters in a 5G network, the RF (Radio Frequency) energy emitted by these transmitters is significantly lower than that emitted from cell towers developed for 2G-4G networks.[12]

Leading international standard setting organizations and regulatory agencies which set health and safety standards for wireless networks and devices include the Institute of Electrical and Electronics Engineers (IEEE)[13] , the International Telecommunications Union (ITU) [14], World Health Organization (WHO)[15], US Federal Communications Commission (FCC). [16]

Since the 1980s - when commercial cellular services were first mass marketed[17], there have been concerns raised by consumers globally and in Canada, regarding potential hazards from the emissions of radiofrequency (RF) energy as well as the cumulative effects of all wireless devices[18].

These concerns have led to debates around the IEEE and WHO standards and extensive studies of RF energy[19] emissions from cell towers and from the mobile devices. While a few studies have raised doubts about RF emissions[20], the consensus among scientific researchers and public health authorities is that wireless networks and devices – including 5G, do not pose a public health risk. A recent, comprehensive study concluded: "*the widely perceived health risks that are attributed to 5G are not supported by scientific evidence from communications engineering*".[21]

In Canada, Industry Canada (ISED) sets stringent standards for RF emissions for all emitting devices including cell phones and towers[22], which concord with those of international organizations such as the IEEE, ITU and FCC. Similarly, Health Canada sets RF standards for devices under its Safety Code 6 under its public health mandate.

Both ISED and Health Canada have concluded that the RF emissions – including those from 5G networks, do not pose a danger to the public.

Health Canada's review of scientific public health studies in Canada and internationally concluded that health impacts associated with exposures to 5G networks and devices are well below its Safety Code 6 standards.[23]

3. The Need for Digital Access Strategy for the Halton Region

The 5G wireless network technologies are currently being deployed in the global marketplace. With the development of complete 5G standards in 2018-19, the telecom operators in Canada recently started the commercial deployment of 5G networks, following pre-commercial tests started in 2017.

In this study, we will demonstrate that 5G network technologies will have a transformative effect on employment, productivity, and GDP in the different sectors of the economy. It is worth noting that the investment in the next generation of both wireline and wireless broadband networks is mainly led by the private sector telecom operators in Canada. As with previous communications technology windows, it is likely that 5G networks in Canada will also be deployed first in large metropolitan areas with progressive deployments along the transportation corridors and smaller centres. It is also likely that 5G will co-exist with 4G networks for a few years given the major Canadian operators recently (starting in 2012) made significant investments for deployment of their 4G LTE and LTE Advanced networks. Therefore, it is expected that LTE will remain the baseline technology for wide-area broadband coverage.[24] This will also allow the wireless network operators to continue to realize their return on their 4G LTE investment.

In this context, it is critical for the Region to implement an effective digital access strategy to ensure it is not left behind from its peers in the adoption of 5G enabled technologies, which will be instrumental for sustainable growth in the emerging digital economies.

The main purpose of this study is to demonstrate to the Region's key stakeholders the critical importance of digital access strategy for deployment of both wireline and wireless broadband networks, which in turn, will enable the economic potential of 5G services and applications - as measured by GDP and employment impacts and sustainable economic growth.

For this purpose, the study aims to fulfill five broad sequential milestones:

1) Establish an **economic baseline status** of digital economic activities in the Halton Region and its four municipalities namely Burlington, Oakville, Milton & Halton Hills. This part of the of study will include a thorough retrospective assessment of the state of Digital economy (2016- 2020) in Halton and four municipalities.
2) Conduct **gap analysis - digital infrastructure readiness assessment** to identify the key prospects and challenges of digital economy in Halton and municipalities.
3) Identification of options for the Region to implement the next generation broadband connectivity
4) Assess the **socio-economic impact of 5G adoption** through its various use cases on other sectors of Halton Region & the municipal economy.
5) Recommended digital access action plan.

3.1 Current Economic Baseline

As a result of rapid technological advancements in recent years, the domain of the digital economic sector has stretched beyond the use of information & communication technologies (ICT) to include several other verticals like *digital intermediary platforms* and *digitally delivered goods*, as shown in Figure 2 below.

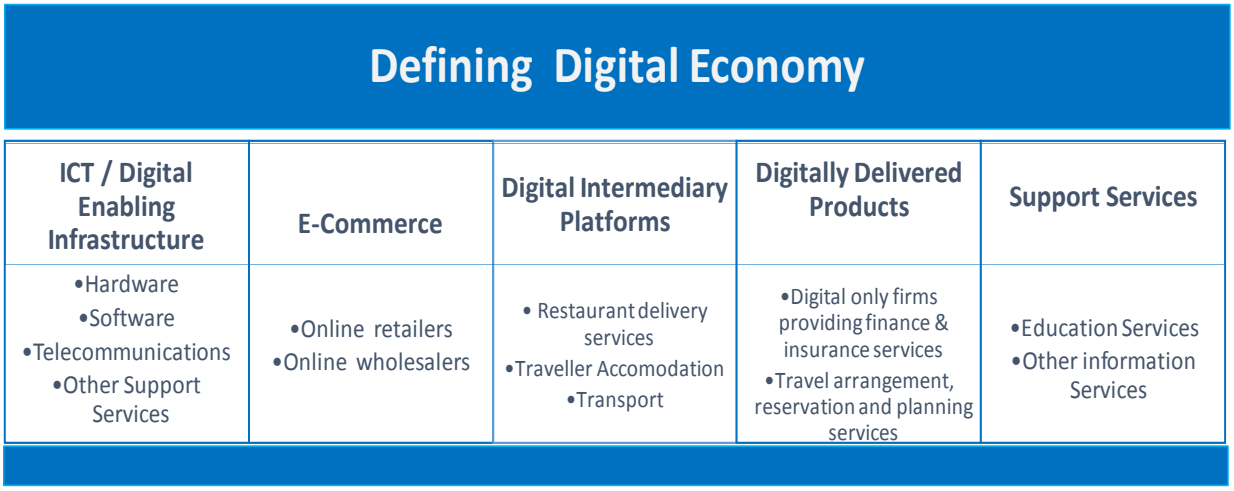


Figure 2: Pillars of the digital economy

An understanding of key elements (verticals) of the digital economy is thus critical in measuring its impact across the region. This study borrows heavily from definitions and concepts of the digital economy used by Statistics Canada[25], U.S. Bureau of Economic Analysis[26] , and the vast literature on digital economy measurement published by the Organisation of Economic Co-operation and Development (OECD)[27], including its proposed national accounting framework for measuring digital economy sectors as distinct satellite accounts.[28]

3.1.1 Defining Digital economy

As shown in Figure 2, the standard Digital Supply-Use framework classifies digital economic activities into the following seven main categories:

- **Digitally delivered products**: Digitally delivered products consist of content transmitted and consumed in digital format. It includes purchasing or renting music and videos, reading books and newspapers, storing photos and documents, or accessing banking services online
- **E-commerce**: E-Commerce refers to the sale of goods or services where the order is received and the commitment to purchase is made via the Internet. The goods or services are ordered via online methods, but the payment and ultimate delivery of the goods or services do not have to be conducted online.
- **Hardware**: Hardware is an important component of Digital Enabling Infrastructure. It consists of the manufactured physical elements that constitute information & communications systems
- **Software**: Software is also categorized as a part of Digital Enabling Infrastructure which includes the programs and other operating information used by computing devices and servers.
- **Support services**: Support Services are an important component of digital economy that includes services necessary for digital infrastructure such as education services, consulting services and computer repair services. A portion of these services like computer repair & maintenance services form a part of Digital Enabling Infrastructure.
- **Telecommunications:** The equipment and services required for the digital transmission of information over a distance by cable, telegraph, telephone, broadcasting, or satellite. Telecommunication goods and services are also considered as Digital Enabling Infrastructure

- **Digital Intermediary Platforms**: Digital intermediary platforms provide links between the service providers and users. These platforms are set up purely to act as intermediaries, matching buyers, and sellers, where typically one or the other pays an intermediation fee; and those that are set up as electronic retailers.

A well-defined classification of digital sector based on the nature of the economic activity is critical in ensuring consistency in the evaluation of the digital economy's contribution to economic growth and for comparative analysis with other sectors and other jurisdictions. The digital categories - listed above, are then mapped to the economic sectors according to the North American Industry Classification Systems (NAICS).

The North American Industry Classification System (NAICS) of all economic activities has been widely used by countries as an international standard to classify data according to economic activity in economic statistics, such as for production or national income, employment, population, and others.

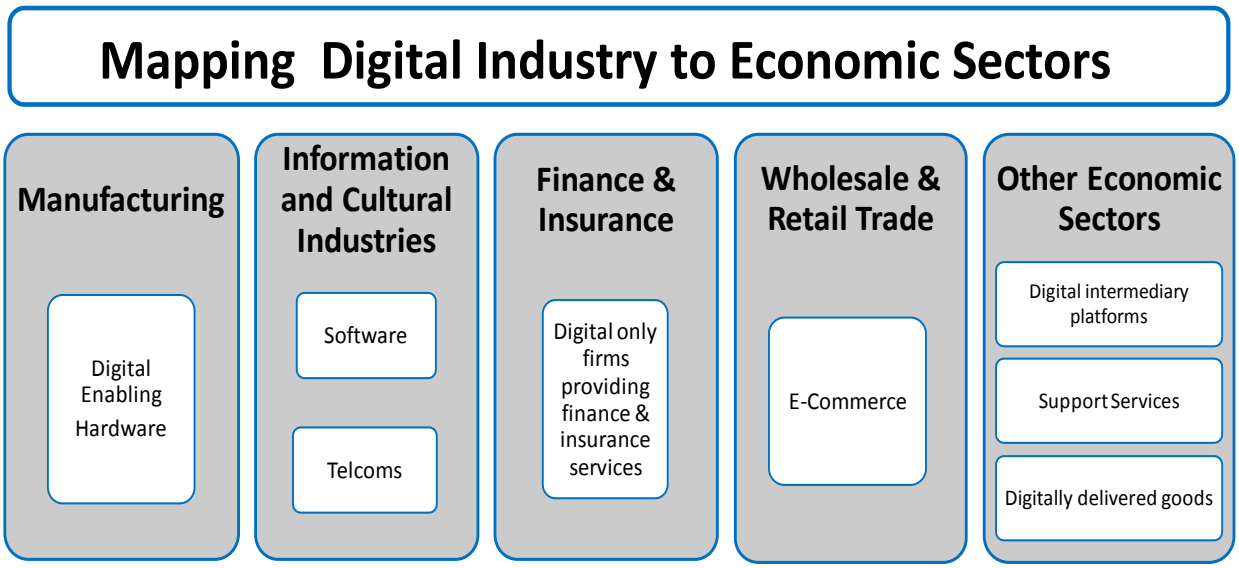


Figure 3: Digital Mapping to ISIC Economic Sectors

This mapping exercise will enable us to understand the cross-sector linkages formed by the digital industries with the other sectors of the Halton economy & municipalities.

3.1.2 Sizing Halton's Economy (GDP)

As shown in Figure 4 below, Halton's GDP witnessed a steady increase from $24.0 billion in 2016 to $26.2 billion in 2019, before exhibiting a decline to $25.4 billion in 2020 principally due to Covid 19. A similar pattern was observed in all municipalities except Oakville where the GDP increased throughout the 2016-2020 period from $9.3 billion (2016) to $10.4 billion (2020).

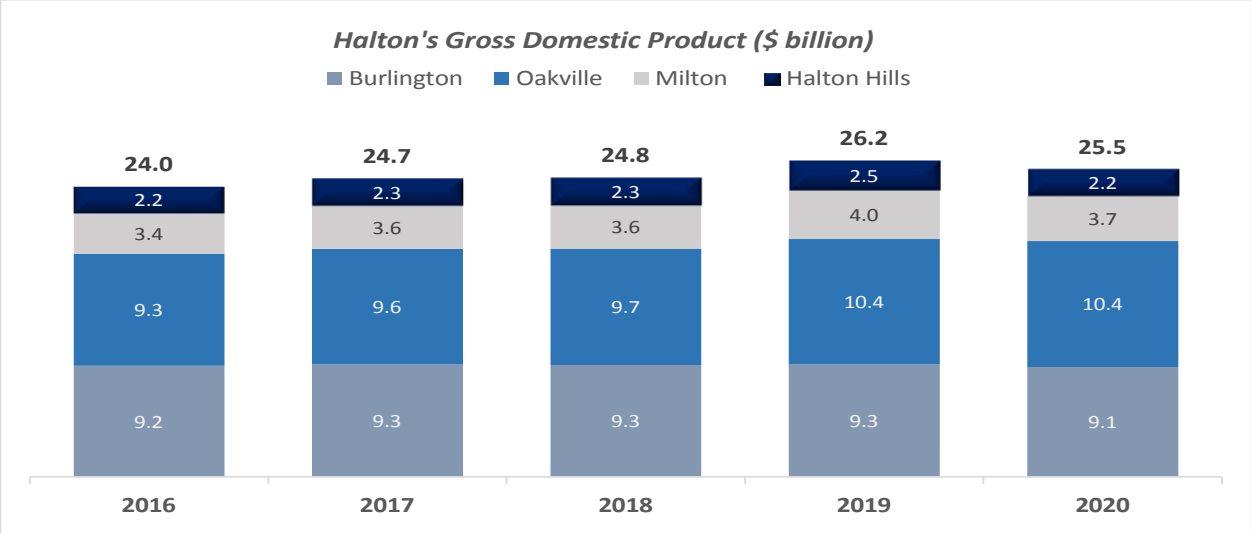


Figure 4: Halton Region's Domestic GDP
Source: Nordicity's calculations based on Halton Employment Survey & Statistics Canada Data

The impact of Covid 19 was also reflected in the distribution of GDP among various economic sectors. As shown in Table 2, sectors like "*Transport and Warehousing*", "*Arts, Entertainment & Recreation*", "*Management of Companies, and Enterprises*", and "*Accommodation & Food Services*" were worse hit, presumably due to shutdowns caused by the pandemic.

Table 2: Halton's GDP Mix (2016-2020)

Economic Sectors	Halton					
	2016	2017	2018	2019	2020	Growth (CAGR)
Manufacturing	$4.49B	$4.33B	$4.22B	$4.65B	$4.11B	-2.18%
Wholesale trade	$1.47B	$1.61B	$1.43B	$1.41B	$1.36B	-1.89%
Retail trade	$1.57B	$1.66B	$1.69B	$1.71B	$1.87B	4.38%
Transport and Warehousing	$1.00B	$1.02B	$0.98B	$1.00B	$0.73B	-7.58%
Information and cultural industries	$0.94B	$0.92B	$1.04B	$0.98B	$1.03B	2.27%
Finance and insurance	$1.72B	$1.92B	$1.74B	$1.98B	$2.20B	6.32%
Management of companies and enterprises	$0.54B	$0.51B	$0.49B	$0.35B	$0.22B	-20.37%
Professional, scientific, & technical services	$1.86B	$1.86B	$1.89B	$2.11B	$1.84B	-0.31%
Admin. support, and waste mgt. etc.	$0.32B	$0.36B	$0.33B	$0.36B	$0.32B	0.60%
Education services	$1.70B	$1.85B	$1.83B	$1.78B	$1.71B	0.21%
Arts, entertainment, and recreation	$0.40B	$0.40B	$0.43B	$0.46B	$0.26B	-10.25%
Accommodation and food services	$0.54B	$0.56B	$0.55B	$0.58B	$0.42B	**-5.81%**
Other Services	$0.65B	$0.68B	$0.68B	$0.74B	$0.67B	0.82%
Remaining sectors	$6.83B	$7.04B	$7.46B	$8.08B	$8.66B	6.10%
Total	**$24.03B**	**$24.71B**	**$24.76B**	**$26.19B**	**$25.40B**	**1.40%**

A detailed account of GDP distribution by economic sectors for four municipalities is presented in Appendix A

3.2 Halton's Digital Economy (GDP)

The digital sector is considered to be a catalyst of economic growth and hence its contribution in terms of its share in the overall economy reflects upon the sector's strength in driving Region's GDP growth. Halton's overall GDP increased by 1.40% per year (see Table 2 above), from $24.0 billion in 2016 to $25.5

billion in 2020. However, as shown in Figure 5 below, the share of its digital sector almost remained constant – *slightly increased from 9.2% (2016) to 9.3% (2020)*.

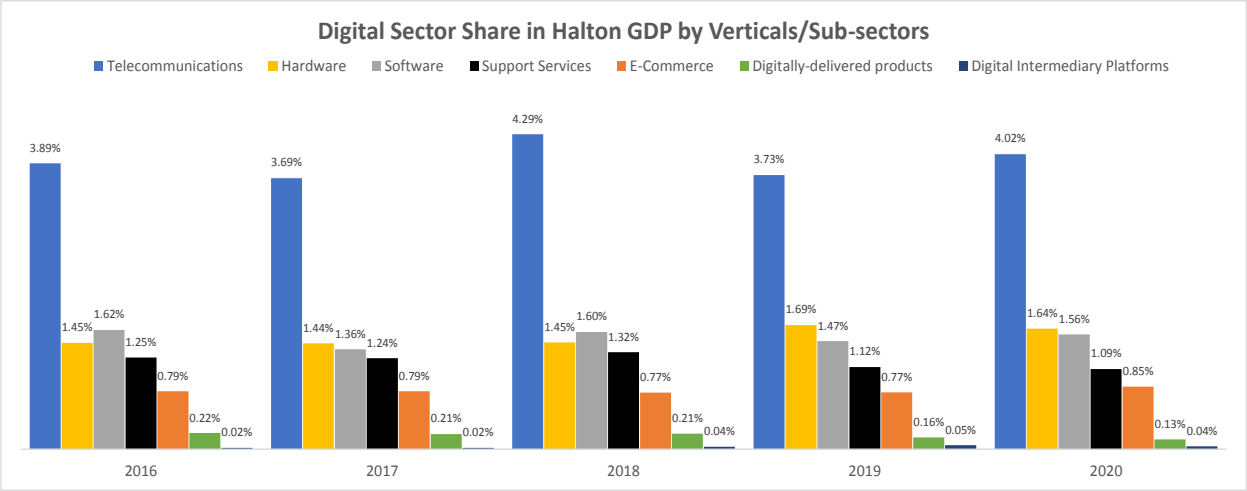


Figure 5: Digital Sector Share in Halton GDP by verticals/sub-sectors

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables.

Note: A detailed account of Digital GDP impact by verticals for the four municipalities is presented in Appendix B.

For better understanding of the economic trends that steered the performance of the Region's Digital Sector in 2016-2020, the Figure 5 above provides its breakdown verticals/sub-sectors. The largest contributor has been the *Telecommunications* sector with its share of about 4.02% in 2020 followed by *Hardware* (1.64%), *Software* (1.56%), *Support Services*, (1.09%), *E-Commerce* (0.85%). The contribution of *Digitally-Delivered Products* and *Digital Intermediary Platforms* has been minimal (below 0.15%).

Although share of Digital sector in the Region's employment has been relatively lower at around 7.2% in 2016-2020, similar trends were found in terms contribution of vertical/sub-sectors as shown Figure **6** below.

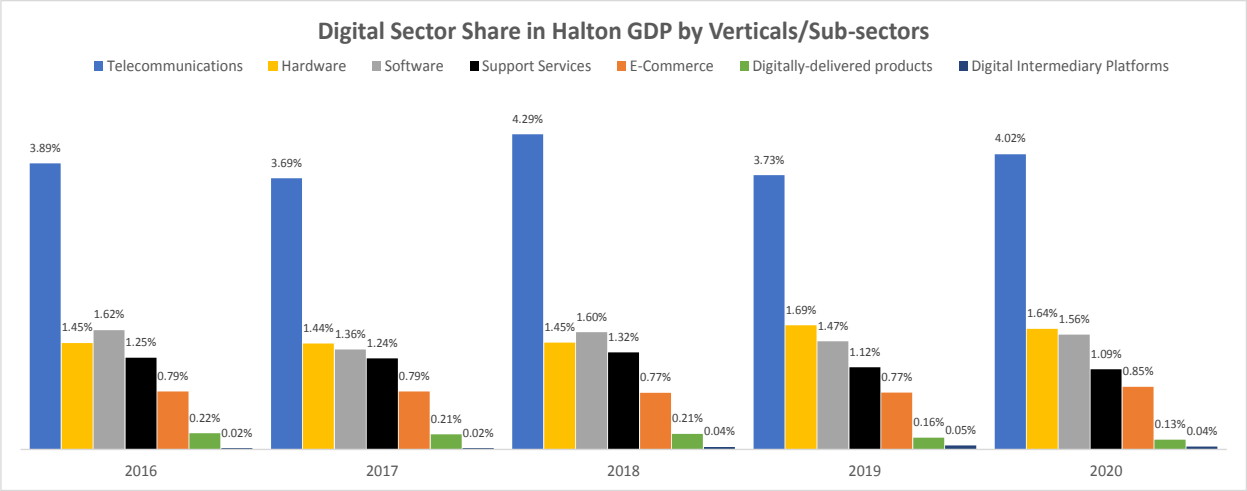


Figure 6: Digital Sector Share in Halton Employment by Verticals/Sub-sectors

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables

A detailed account of Digital Employment impact by verticals for the four municipalities are presented in Appendix C.

It is worth noting that while Telecommunication is the key enabler of digital infrastructure the role of sub-

sectors such as ***Software, E-Commerce, Support Services, Digitally Delivered Products,*** *and* ***Digital Intermediary Platforms,*** will be instrumental role in future economic growth given. As demonstrated in the following section these sectors produce higher value-added products and services (GDP per worker) and create highly paid jobs.

3.3 Productivity Impact Analysis

Productivity estimates have been long recognized as an important contributor to income growth and economic development. There has been an accentuated focus to explore the relationship between economic growth and factor productivity of different sectors of the economy.

Factor productivity serves as an indicator of the overall economic performance of the sector and provides useful insights for policymaking and investment decisions.

This study provides estimates for labor productivity as a key measure of the economic performance of the Halton's digital sector. Labour productivity is defined as output per labor input[29]. A review of the current productivity levels across Halton's digital economy is instrumental in understanding the extent of 5G's impacts on the sales enablement and economic growth in future. As GDP and output are used interchangeably in economic literature, this study produced productivity estimates by calculating GDP generated per worker for the Digital sector[30].

As an expected outcome of digitization, productivity gains were realized in each sub-sector/vertical of Halton's digital economy during 2016-2020. The increase in productivity is attributed to increased automations of operations and higher value jobs in the sector. As shown in Figure 7, GDP per employee growth was highest for Digital Intermediary platforms (5.2%) followed by Digitally Delivered products (2.4%), E-Commerce (2.3%), Support-Services (2.1%), Software (1.6%), Hardware (0.85%) and finally telecommunications (0.5%). Of the four municipalities, Milton's overall digital productivity exhibited highest compound annual growth (2.25%) followed by Burlington (1.57%), Halton Hills (1.32%) and Oakville (1.19%).

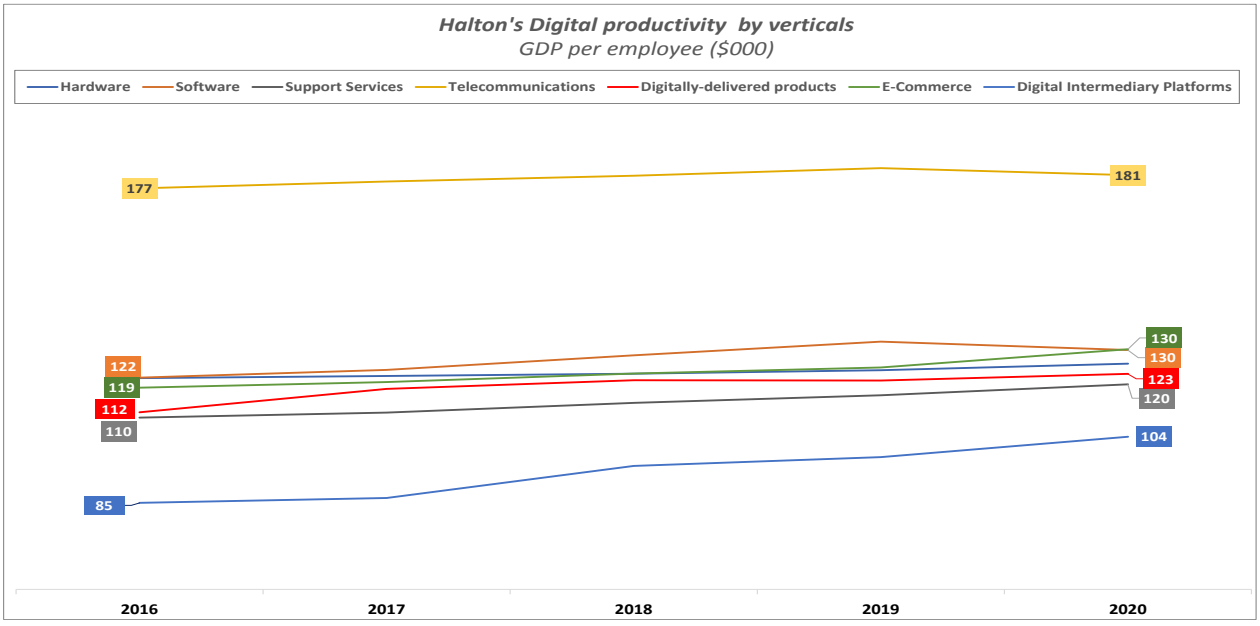


Figure 7: Halton's Digital Productivity by verticals/sub-sectors

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables

A detailed account of Digital Productivity impact by verticals for the four municipalities is presented in Appendix D.

4. Digital Infrastructure Readiness Assessment

4.1 Broadband Connectivity - Current Status

The analysis presented in Section 3 above provides the baseline and helps identify key challenges and opportunities for each municipality in terms of economic growth and productivity, i.e., how 5G enabled services and applications can help address economic challenges and create new development opportunities for long term sustainable economic growth for the Region. As noted above, the availability of next-generation high speed broadband connectivity (wireline as well as wireless) network across the Region will be critical to enable the economic benefits of 5G technologies. In other words, a fully integrated viable broadband network is critical for provision of reliable internet services for the Region's sustainable economic development. **That is, in order for 5G wireless network to be able to offer exponentially higher (1 Gig+) speeds and capacity, the wireline network must also improve proportionately[31].**

In this context it has been recognized by the CRTC[32], and many other Canadian jurisdictions[33] that a modern broadband infrastructure is a critical enabler for widespread availability of high-speed internet services and correspondingly, digitally enabled citizenry, as well as innovation and growth in all sectors of the economy.

However, in terms of the internet speed targets presently set by the CRTC, all Canadian homes and businesses should have access to the broadband Internet speeds of at least 50 Mbps for downloads and 10 Mbps for uploads with the option for unlimited monthly data transfer. According to the ISED data about 96% of the 198K households in the Region appear to have access to fixed broadband internet services with speed of 50/10 Mbps or more – see Table 3 below. That is only 6,998 (3.5%) households are under that threshold or are not served, including 2,587 in Halton Hills (12%), 2,569 in Milton (7.2%), 1,325 in Burlington (1.8%), and 517 Oakville (0.8%).

Table 3: Halton Region – Fixed (Wireline) Broadband Coverage

Wireline Broadband Coverage		Oakville		Burlington		Milton		Halton Hills		TOTAL	
Households	Total	68,634	100.0%	72,555	100.0%	35,554	100.0%	21,481	100.0%	198,224	100.0%
	50/10 or more	68,117	99.2%	71,230	98.2%	32,985	92.8%	18,894	88.0%	191,226	96.5%
	Under Served	517	0.8%	1,325	1.8%	2,569	7.2%	2,587	12.0%	6,998	3.5%
Population	Total	193,805	100.0%	183,212	100.0%	109,936	100.0%	61,233	100.0%	548,186	100.0%
	50/10 or more	192,475	99.3%	179,222	97.8%	103,164	93.8%	53,805	87.9%	528,666	96.4%
	Under Served	1,330	0.7%	3,990	2.2%	6,772	6.2%	7,428	12.1%	19,520	3.6%
Area (KM^2)	Total	139	100.0%	190	100.0%	366	100.0%	275	100.0%	970	100.0%
	50/10 or more	79	56.8%	57	30.0%	58	15.8%	50	18.2%	244	25.2%
	Under Served	60	43.2%	133	70.0%	308	84.2%	225	81.8%	726	74.8%

Source: Nordicity's calculations based on ISED's Broadband Coverage Database

It is worth noting that although ISED Broadband Coverage data show that while 96% of Region's current population – as currently distributed, has 50/10 Mbps speeds via fixed infrastructure, this coverage is only available in 25.2% (244 Sq. km) of Halton region's total area of 970 Sq. Km – see Figure 8 below.

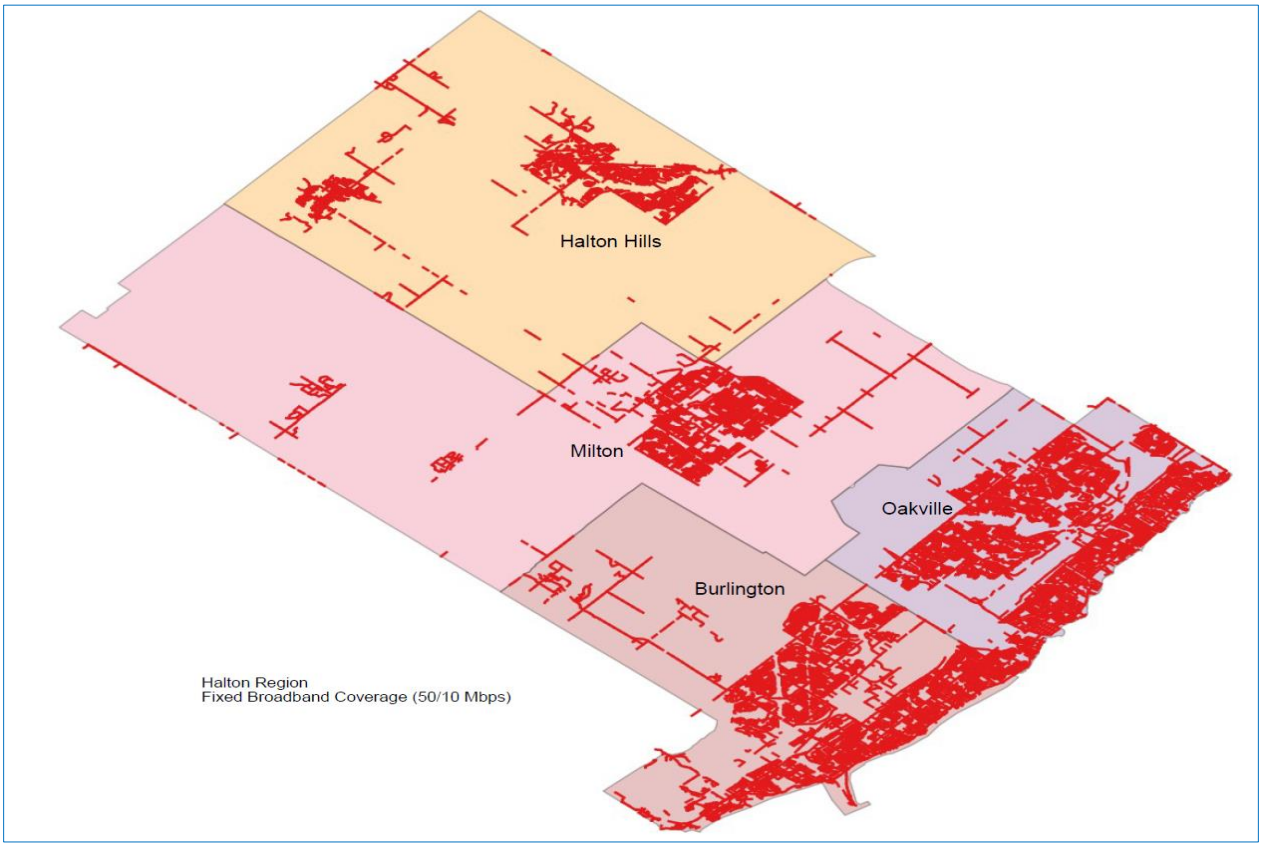


Figure 8: Halton Region - Wireline Broadband Coverage Area
Source: Nordicity's calculations based on ISED's Broadband Coverage Database

With 25% of the Region's total area covered by the fixed broadband services with the internet speed of 50/10 Mbps, we believe the benefits of 5G wireless network capability will be only partially realized, i.e., restricted to the high population density (urban) areas.

We also believe that in terms of availability of fixed (wireline) internet services, the ISED Broadband Coverage data appear to overstate the availability of broadband coverage - as explained below.

4.2 Broadband Connectivity – Gap Analysis

The internet service providers (ISPs) that provide fixed broadband services across Canada mainly use the following four broad categories of technologies:

DSL	**Digital Subscriber Line (DSL)** is a legacy technology, and its further deployment has been universally discontinued. Furthermore, given its constraint, this technology is not considered as a practical solution for the provision of high-speed Internet in low density rural areas - *the maximum speed this technology can deliver is approximatively 50 Mbps, only under specific conditions and contingent on the subscriber being located within 2km from the Central Office (CO).*

DOCSIS	**Data Over Cable Service Interface Specification (DOCSIS)** is a broadband technology used by cable-based carriers (such as Rogers, Cogeco) to deliver high speed internet services using Hybrid Fibre Coaxial (HFC) cable network. This technology meets the current requirements set by CRTC for 50/10 Mbps as well as future midterm needs but not the ultimate goal of 1Gbps in the anticipated long-term evolution of broadband speed standards. For example, according to CRTC's 2020 Communications Monitoring Report, *fibre-based gigabit services have far faster upload speeds than their DOCSIS-based counterparts* (p.104)
FTTH/P	**Fibre to the home/premise (FTTH/P)** with the Gigabit-Passive-Optical-Network (GPON) architecture and to be released GPON2 (NG-PON2/10G-PON) is the most typical wireline deployment in recent years. GPON can deliver up to 1Gbps to a subscriber, without any constraints. In the future, GPON2 will be able to deliver between 2.5Gbps to 10Gbps to a subscriber. Furthermore, as noted above fibre based (GPON) services have far faster upload speeds than those delivered through DOCSIS based technology.
FWA	**Fixed Wireless Access (FWA)** is an interesting and efficient solution for the deployment of internet connectivity in less densely populated areas. However, similar to DSL technology, it is rarely possible to reliably obtain speeds of 50/10 Mbps with technologies using unlicensed frequencies (2.4 GHz or 5 GHz Wi-Fi). Technologies such as LTE (Long Term Evolution), licensed frequencies, and a robust design may allow them to obtain higher speeds and more stable performances. However, it is unlikely to be able to meet the current broadband demands for larger industries and MUSH institutions. Critically, FWA will not allow service providers to scale up to ISED and CRTC goal 1 Gbps service in the future.

The main ISPs currently providing internet services in the Region include:

- **Bell** provides internet services using DSL, and FTTH/P technologies. It is worth noting that according to the CRTC, FTTH/P based internet services are only available to 45% of the Canadian households which are mainly in the large urban areas such as GTA, MTA, Vancouver, Calgary (see CRTC CMR 2020, p. 51). This means, Bell's FTTH/P deployment in the Region is limited to high density (more than 100 households per sq. km) areas. Therefore, it is reasonable to assume that the remaining vast majority of the households are served through DSL and/or DOCSIS (Cable) technologies.
- **Rogers**, as mentioned above delivers high speed internet services, using DOCSIS - Hybrid Fibre Coaxial (HFC) cable network, to mainly high-density household areas.
- C**ogeco** also as mentioned above delivers high speed internet services, using DOCSIS - Hybrid Fibre Coaxial (HFC) cable network, to mainly high-density household areas.
- **Standard Broadband**, provides internet services using FTTH/P technology but only in Ballinafad (Halton Hills), and Moffat and Brookville (Milton)
- **Xplornet** provides internet services mainly using FWA (Fixed Wireless Access) technology.

Although the ISED data indicates that about 96% of the 198K households in the Region to have access to fixed broadband internet services with speed of 50/10 Mbps or more, we believe it is critical to further examine state of broadband coverage in the Region. In our view, 96% coverage is based internet speeds offered by the service providers. This means if a service provider offers a 50 Mbps download speed it is based on a "best effort" service model, which usually refers to an "up to" or "average" speed promise. In other words, the actual internet speed delivered to the subscribers can be significantly lower than the promised speed. In this sense, it is important to examine the reliability of speed offered by the service providers, which depends on different factors such as:

- **Broadband Technology**: The broadband network technology (DSL, DOCSIS, FTTH/P, FWA etc.) used to deliver internet services can significantly influence delivery of internet speed. For example, on a DSL/FWA platform the internet speed decreases as the subscribers are further away from the service hub (central office/cell site). The internet speed can decrease significantly on DSL, and FWA networks, if the subscribers located beyond a certain distance. For example, it becomes very challenging for service providers to deliver more than 25Mbps speed on a DSL network to a customer located beyond 1 Km from their service hub.
- **Oversubscription Rate:** Oversubscription rate refers to the ratio used by the telecom operators to dimension their broadband service/network. It refers to the assumption that not all subscribers will demand peak service e.g., 50 Mbps at the same time. Typically, wireline network operators assume only 10% to 20% of the subscribers will demand peak service at the same time. Broadband service speed can significantly decrease if the actual ratio of those subscribers exceeds the oversubscription rate assumed by the telecom operator. In such situation, it is difficult to deliver reliable internet service if the broadband network lacks flexibility and scalability for upgrade e.g., DSL, DOCSIS, and FWA.
- **Quality of Service (QoS):** The quality of service refers to the ability of the broadband network to maintain a performance level (e.g., internet speed) required for a reliable delivery of different service applications such as IP-TV, Videoconferencing, telemedicine etc. For example, a constant internet speed of 15-25 Mbps is required for uninterrupted delivery of IP-TV service, depending on whether it is a Standard Definition (SD), High Definition (HD), or 4K etc., video service. For example, 1-2 HD TVs on a DSL platform can significantly degrade broadband speed offered by ISPs when used at the same. FTTH/P (wireline), and 5G (wireless) technologies would only meet QoS level required for critical applications in the emerging digital world.

In this context we further examined the ISED data for the broadband coverage in the Region. Using ISED, Census Canada geomatics data we first categorized the Region's households according to five density levels as below.

Density Level	Definition
Very Low Density	<=Less than 10 Households per KM^2
Low Density	> 10 to <=25 Households per KM^2
Medium Density	> 25 to <=50 Households per KM^2
High Medium Density	> 50 to <=100 Households per KM^2
High Density	> 100 Households per KM^2

Then we assigned coverage (internet speed) to each density level, according to the characteristics of the available network technologies described above. For example, according to CRTC FTTH/P based internet services are mainly deployed in large urban areas. On this basis, we assumed high-density areas in the Region would likely have FTTH/P, and therefore meet or exceed the CRTC speed target of 50/10 Mbps. For the other four density levels we assigned internet coverage speeds based on our industry experience and knowledge on similar project, some involving field surveys of broadband infrastructure[34].

On this basis we estimate that less than one third (30.6%) of the households in the Region may have access to reliable internet services potentially meeting the CRTC target speed of 50/10 Mbps or more - see Table 4 below.

The five ISPs listed above mainly deliver internet services to households in the Region using FTTH/P, DSL and DOCSIS-HFC technologies. As explained above, only FTTP/P (using GPON technology) can deliver up to 1Gbps to a subscriber, without any constraints. That is, only 21,613 (10.9%) of the households in the Region may have access to a future proof fixed broadband internet services including 1,118 in Halton Hills (5.2%), 3,609 in Milton (10.2%), 4,832 in Burlington (6.7%), and 12,054 Oakville (17.6%).

Table 4: Halton Region – Fixed (Wireline) Broadband Coverage by Internet Speed

Broadband Coverage by Technology	Oakville		Burlington		Milton		Halton Hills		TOTAL	
FTTH/P	12,054	17.6%	4,832	6.7%	3,609	10.2%	1,118	5.2%	21,613	10.9%
50/10Mbps	18,845	27.5%	5,500	7.6%	9,236	26.0%	5,494	25.6%	39,075	19.7%
Below 50/10Mbps	27,518	40.1%	10,412	14.4%	16,483	46.4%	8,731	40.6%	63,144	31.9%
25/5Mbps	10,027	14.6%	46,162	63.6%	5,979	16.8%	6,032	28.1%	68,200	34.4%
Below 25/5Mbps	190	0.3%	5,649	7.8%	247	0.7%	106	0.5%	6,192	3.1%
Total	68,634	100.0%	72,555	100.0%	35,554	100.0%	21,481	100.0%	198,224	100.0%

Source: Nordicity's estimates based as based on the analysis of household density per square kilometer using ISED Census Canada, and MPAC data.
Note: Given the methodology applied, the broadband coverage for the new sub-divisions developed in 2015 or later (which are likely to be served with FTTH/P) may not have been properly represented in our above assessment.

Based on our estimates almost 90% of the households currently do not have access to internet services with speeds of 50/10 Mbps or more, using future proof (FTTH/P) fixed broadband.

We believe the impacts of the weakness in broadband coverage will grow significantly in the future.

According to CRTC's CMR report (2020), Canadians continue to use more data, subscribe to faster, larger packages and allocate more money to Internet access services (p. 51). That is, with the exponential growth in broadband usage, it is likely that in the near future, the demand for internet speeds will be significantly higher than 50/10 Mbps, reaching up to Gigabit[35] service in the Region.

We believe also that based on current trends of broadband usage it is reasonable to believe that demand for internet speeds will reach up to 1 Gbps in the medium term. We also believe that businesses, industry, and MUSH (Municipalities, Universities, Schools, and Hospitals) institutions are likely to require 1 Gbps or higher speed internet services. Similarly, residential, including self-employed and work-from-home, demand is also expected to increase exponentially, ranging between 100 Mbps and 1 Gbps.

That is, the availability of reliable and scalable high-speed internet services is not only essential to meet the emerging demand for high-speed internet connectivity but also for the enablement of digital infrastructure in the Region to assure its long term sustainable economic development. In other words, the presence of a modern digital infrastructure is becoming increasingly critical to achieve the objectives of inclusive prosperity, tackling social and governance challenges and enriching citizens' quality of life.

The sectors that play an instrumental role in achieving this objective include *businesses*, *agriculture*, *education*, *health*, and *public safety*. Correspondingly, the *availability of broadband networks can have a significant impact on the performance of these sectors, as illustrated below*.

Business	– Broadband is critical for businesses to improve their productivity and efficiency to remain competitive. – Adequate broadband connectivity is essential to attract new business and retain existing business
Agriculture	– Transition to smart agriculture and smart farming is critical to remain competitive. – This requires broadband infrastructure to leverage advanced technologies in farming such as big data, cloud computing, internet of things (IoT) for tracking, monitoring, automating, and optimizing operations.
Education	– Access to high-speed internet and online applications are becoming increasingly important for high quality education. – Modern educational technologies including application such as augmented reality (AR), virtual reality (VR) depend on high-quality broadband services, at school and at home
Workforce	– Reliable access to online applications are becoming increasingly important to improve workforce efficiency and competitiveness
Health	– Efficient functioning of health care services - *eHealth*, *telemedicine* is becoming increasingly dependent on high-quality broadband capability e.g., connecting with patients virtually for remote consultation, monitoring and some medical procedures.
Public Safety	– High quality broadband capability is critical in a modern community to ensure effective response to emergencies, and public safety incidents, without any delays.
Government Services	– Reliable broadband enables more effective interaction with citizens and more efficient delivery of public services.

5. Next Generation Broadband Connectivity Implementation Options Analysis

Based on the assessment presented in the previous section, we believe significant gap exists in most parts of the Region in terms of broadband capability in meeting the emerging demands for reliable and scalable highspeed services in a digital (1Gig+) economy. That is, in most cases 50/10 Mbps speed is delivered through copper-based Digital Subscriber Line (DSL) or cable-based Data Over Cable Service Interface Specification (DOCSIS) wireline networks. As stated above, DSL is a legacy technology, and its further deployment has been universally discontinued. DOCSIS technology (used by Rogers, and COGECO) delivers high speed internet services using Hybrid Fibre Coaxial (HFC) cable network. Although this technology meets the current requirements set by CRTC for 50/10 Mbps and future midterm needs, it lacks the scalability to deliver reliable speed of 1 Gbps plus in the anticipated long-term evolution of broadband speed standards.

As such, the technological limitation of existing broadband networks could significantly inhibit the full realization of the benefits of 5G enabled services in the Region. To address this gap, we present the following three options for consideration.

- Status Quo Model
- Status Quo with an Accelerated FTTH/P Deployment
- Unified FTTH/P Deployment[36]

5.1 Status Quo Model

The status quo model assumes the existing ISPs and potentially new entrants will continue to upgrade their existing broadband networks to meet the growing demand for internet services with higher speed requirements. The main limitation of this option is that it will primarily depend on the level of the interest of the ISPs to upgrade their broadband network capabilities. Typically, ISPs implement network upgrades on an incremental basis, depending on their ability to retain subscribers in the face of competitors' comparative capabilities and the opportunity to gain market share and higher subscriber revenues. That is, ISPs will only consider FTTH/P deployment where it is feasible from their financial perspective e.g., higher density areas ensuring return on investments expected by their shareholders, and/or where they anticipate a significant gain or loss in their market share. Under this status quo

approach, it will likely take several years (at least 7 to 15 years) for ISPs to meet the demand for high-speed internet connectivity on equitable basis for all the residents across the Region. This option will also restrict the full realization of economic benefits of 5G technologies across different sectors of the Region's economy – *5G rollout will be restricted to the deployment of small cells only to enable operators to support more subscribers with faster speed without the need to acquire additional spectrum.* Therefore, we believe the wireless network operators (MNOs) in the Region such as Bell, and Rogers will likely focus on 5G (small cell) deployments to enhance their wireless network capacity mainly in high density areas and along transportation corridors to meet the needs of their mobile broadband subscribers who are demanding faster speed and more data.

5.2 Status Quo with an Accelerated FTTH/P Deployment

The objective of this option is to accelerate FTTH/P deployment where required, to ensure all of residents have access to the internet services with similar speeds across the Region. For this purpose, we propose that the Region, in collaboration with the telecom network operators, advocates for funding through public sources to subsidize the higher cost of FTTH/P deployment in low density areas.

As in the case of Status Quo Model this option also has similar limitations. For example, it will primarily depend on the level of the interest of the ISPs to upgrade their broadband network capabilities in the lower density areas. However, depending on the availability of provincial and federal funding programs and their eligibility criteria, this option will accelerate the FTTH/P deployment in selected areas of the Region, particularly lower density, and rural areas.

It is worth noting that FTTH deployment cost per household in very low-density rural areas of the Region - representing about 6,192 households, is almost 3 times higher than the deployment cost in medium density areas, as shown in Figure 9 below.

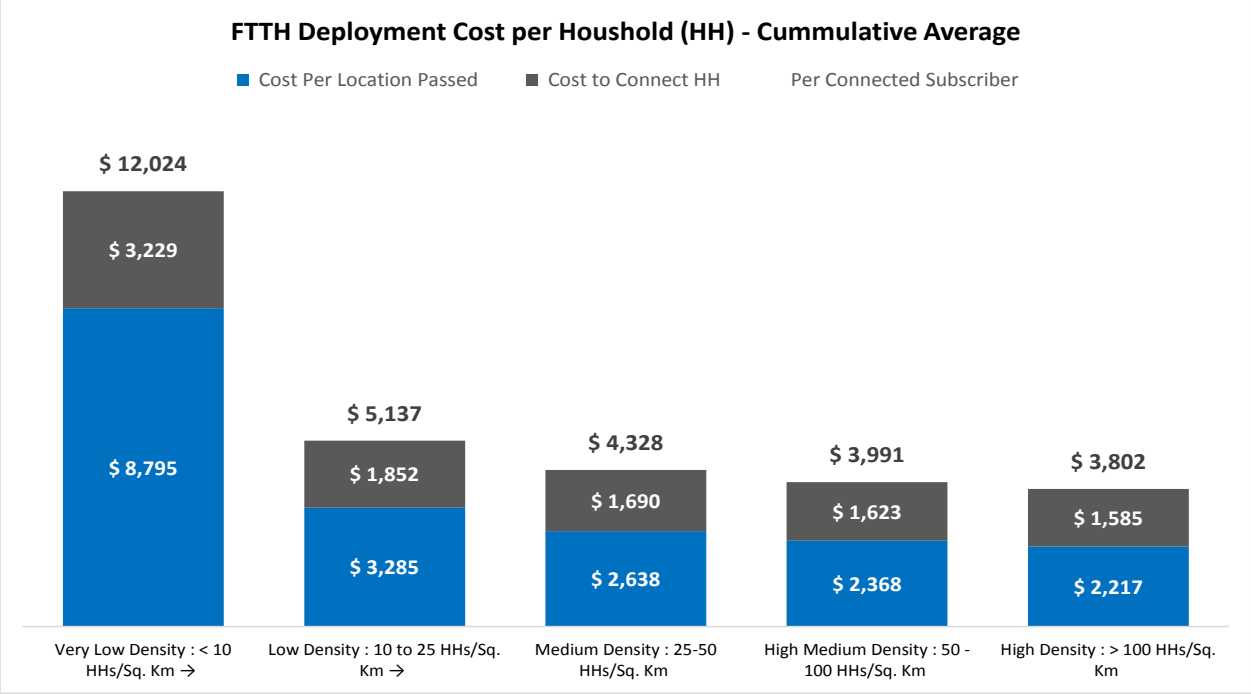


Figure 9: Halton Region – FTTH Deployment Cost per Household

Source: Estimated amounts based on Nordicity's Broadband Investment Model using ISED's Broadband Coverage, Census Canada, GIS data

This option lacks the integrated approach required to fully realize the economic benefits of 5G technologies across different sectors of the Region's economy. Furthermore, as stated above, the wireless network operators (MNOs) such as Bell, Rogers, will likely limit their 5G technology rollout to small cell deployments only to increase their network capacity to meet the growing demand for higher speeds and data from their wireless broadband subscribers, mainly in high density areas and along transportation corridors.

5.3 Unified FTTH/P Deployment

It is worth noting that an initial investment of $54.5m is estimated to be required to serve 6,192 low-density (which are mostly rural areas) with future proof FTTH broadband capacity – costing $8,895 per household or $12,024 per connect household (subscriber). However, in the scenario that a unified FTTH network is deployed across the Region covering 198K households, while total initial investment will increase to $439m, the average FTTH cost per household will be significantly reduced: from $12,024 to $3,802, as shown in Figure 9 above. This means, a significant amount of subsidy per household will be required if FTTH deployment is targeted only to address the connectivity gap for the 6,192 households in low-density/rural areas only.

Table 5: Halton Region – FTTH Deployment Investment Analysis

	Very Low Density: < 10 HHs/Sq. Km	Low Density: 10 to 25 HHs/Sq. Km	Medium Density: 25-50 HHs/Sq. Km	High Medium Density: 50 - 100 HHs/Sq. Km	High Density: > 100 HHs/Sq. Km	Total Region
Estimated households/locations passed	6,192	68,200	63,144	39,075	21,613	198,224
Penetration rate (connected ratio assumed)	80.00%	80.00%	80.00%	80.00%	80.00%	80.00%
Estimated connected households/locations	4,954	54,560	50,515	31,260	17,290	158,579
Average monthly subscription rate	130.62	130.62	130.62	130.62	130.62	130.62
Net present value (NPV)	($49,491,287)	($47,065,254)	$26,249,364	$37,909,743	$32,397,434	-
Payback (years)	Over 25 Years	19	13	10	8	15
Breakeven (NPV=0) monthly rate	**$189.69**	**135.72**	**127.54**	**123.45**	**119.54**	**130.62**
Total initial capex	**$54,460,095**	**$189,914,854**	**$118,393,576**	**$55,433,958**	**$21,259,438**	**$439,461,922**
Rate of Return (assumed borrowing cost)	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**
Study (useful) life	25 Years	25 Years	25 Years	25 Years	25 Years	25 Years
Cost per household/location passed	$8,795	$2,785	$1,875	$1,419	$984	$2,217
Cost per connected household/location	$10,993	$3,481	$2,344	$1,773	$1,230	$2,771
Activation cost per household/location	$1,031	$1,031	$1,031	$1,031	$1,031	$1,031
Total cost per connected household/location	$12,024	$4,512	$3,374	$2,804	$2,260	$3,802

The analysis shown in Table 5 above indicates that it might be more cost efficient to implement a uniform future proof broadband infrastructure across the region, which will permanently address the internet connectivity challenges in the Region. Furthermore, this option will help eliminate the digital-divide and enable equitable realization of the socio-economic benefits of 5G technologies by all the residents in the Region.

This option has been considered by some jurisdictions in Ontario outside GTA such as Northumberland County, Township of Leeds and Thousand Islands, and the City of Quite West. For example, Northumberland considered a utility approach to deploy a unified broadband network across the County

using FTTH/P technology, financed through a combination of public funding and P3 (Public Private Partnership) investment.

Some jurisdictions in Ontario have considered creation of municipally owned dark fibre network – YorkNet. YorkNet, incorporated in 2017 as YTN Telecom Network Inc. is a wholly owned Regional corporation that operates and manages the expansion of the fiber-optic network in York Region. YorkNet currently operates about 400Km of dark fibre along the regional roads, with the objectives including.

- To improve delivery of Region's services (traffic management, transit, infrastructure monitoring and policing).
- To provide a reliable and cost-effective connectivity to municipalities, schools, hospitals, and other public-sector organizations in the Region
- To provide open access to ISPs and business to deliver affordable internet services, particularly in rural areas of the Region.

It seems the main focus of YorkNet is to promote access to and affordability of broadband services – especially in rural areas where the major ISPs have historically delayed the roll out of high speed broadband networks (fixed and mobile) due to lower profitability. We believe YorkNet provides an effective platform for the Region to ensure a unified a broadband capability across the Region. However, it will depend on its ability to collaborate with the ISP in prioritizing their FTTH/P, and 5G network roll outs, and attracting public funding.

The Durham Region has a mixed approach in which it has mostly favoured private investors. For example, it promoted creation of Durham Broadband, which is owned by a group of private local firms, providing dark fibre network access services, like YorkNet, to institutions and businesses across the region.

However, in May 2021 the Regional Council, recognizing that the citizens in many rural areas did not have access to affordable broadband due to the higher costs of service and issues with funding programs, have indicated the desire to play a direct role by deploying a fibre optic backbone network along the regional roads connecting hamlets and rural communities. The purpose of building the fibre optic backbone network is to make it available for lease by the private sector in order to reduce the time and cost required for ISPs to bring service to rural communities.

We believe both York and Durham dark fibre network models may provide an effective platform to ensure a unified broadband infrastructure required for 5G capabilities across the regions. However, it will depend on their ability to collaborate with the ISPs in attracting public funding/investments, and prioritizing their FTTH/P, and 5G network roll outs for the regions.

5.4 Leveraging Region's Pole Infrastructure for 5G Deployment

As part of their 5G roll out plans, the mobile network operations such as Rogers, Bell, and others will need to deploy small cell technology. These small cells are essential for 5G network capability as they allow the operators to support more users with faster speeds without the need to acquire additional spectrum. Small cells are mini cellular towers (antennas), which are roughly the size of a standard laptops, which can be installed on top of the buildings, traffic signals, streetlights, and utility poles. In this context the Region can leverage its existing pole infrastructure (mainly street-light and utility poles) to facilitate faster deployment of 5G network capability. The breakdown of 82,327 poles in the Region is provided in Table 6 below.

Table 6: Halton Region – Vertical Assets (Poles) Inventory

Municipality	Number of Poles by Ownership		
	Hydro (Utility)	Municipal (Street Light)	Combined
Burlington	14,471	11,184	25,655
Halton Hills	9,398	3,569	12,967
Milton	9,799	9,786	19,585
Oakville	8,682	10,293	18,975
Region	-	5,145	5,145
Halton Region	**42,350**	**39,977**	**82,327**

Note: Traffic signal poles, due to operational and technical reasons cannot be used for 5G equipment installation, therefore excluded

The emergent need of wireless operators (mainly Bell and Rogers) for deployment of their 5G small cells presents an opportunity for the Region to partner with the LDCs to effectively utilize their vertical assets (street-light, and utility pole assets as shown Table 6) for a faster rollout of 5G networks. In this context the Halton Utility Group (HUG) has proposed to aggregate Halton's poles for their optimal utilization for 5G small cells deployments.

In our view the HUG proposal presents certain benefits in terms of optimal use of the Region's existing pole infrastructure including:

- Pooling of assets will allow the Region to negotiate more favourable rates, given the critical mass, as compared to municipalities negotiating rates individually.
- The HUG LDCs may effectively manage operations of 5G attachments based on HUG's existing day-to-day working relationship with the network operators. Although, some municipalities may have an existing relationship with the telecom operators for use of their pole infrastructure, they may required a framework to manage the use of their poles for 5G small cells operations. This would mean incremental costs for capacity-building and loss of synergies that may occur under combined operations as proposed by the HUG.

We also believe there are certain risks associated with HUG proposal, which need to be carefully examined and mitigated, as explained below.

- **Utilization Factor Risk**: As mentioned above, the main driver of small cells deployments by the wireless operators is to increase their network capacity to support their mobile broadband users demanding faster speed and more data, which is mainly in high density areas. That is, small cells split the macro coverage areas into smaller coverage areas, which allows the wireless network operators to support their subscribers without the need to acquire additional spectrum. For this purpose, depending on the network capacity requirements, about 4 to 10 small cells are typically needed for every macro cell site. This may mean **small cells deployment in the Region could range from 3,300 to 8,300 representing a maximum pole utilization ratio of 4% to 10% in the next 3-5 years.** This utilization may increase significantly in a fully developed 5G ecosystem, encompassing a massive IoT infrastructure. However, such a scenario would occur in the long run, which will also depend on the overall broadband network capability and roll out of 5G use cases across different economic sectors of the Region. In the scenario with less 10% utilization of total poles for 5G small cells may present revenues risk for the HUG to fully recovering its operating expenses.

- **Regulatory Risk:**

  HUG proposal is based on assumption occupancy fees for 5G small cells will be commercially negotiated. In the recent years, mobile operators in Ontario, agreed to pay LDCs commercially negotiated rates for the installation of wireless on utility poles but only for a relatively small number of their 4G (LTE) cell sites.

  It is worth noting that wireless attachments to utility poles typically have not been subject to any regulations for rate determination, and therefore have been commercially negotiated. That is, there has been no complaints regarding the wireless attachment rates. This is mainly due to the limited number of wireless attachments under the 3G/4G environment. However, with the emergence of 5G technologies the telecom operators are likely to deploy a far greater number of wireless equipment (small cells) to increase their overall network capacity. The standards for wireless cell sites are federally regulated in Canada by the ISED – Ministry of Innovation, Science and Economic Development. In recent years both the Federal and Ontario governments have introduced programs and initiatives to accelerate the deployment of broadband networks particularly in unserved and underserved areas. In October 2020 the CRTC initiated consultation proceeding: CRTC 2020-366[37], stating:

  "The Commission is concerned, based on submissions received in the proceeding initiated by Telecom Notice of Consultation 2019-406, that untimely and costly access to poles owned by Canadian carriers has negative impacts on the deployment of efficient broadband-capable networks, particularly in areas of Canada with limited or no access to such networks. Therefore, the Commission is initiating a proceeding to identify and implement regulatory measures that will make access to such poles more efficient."

  Also, earlier this year the Government of Ontario introduced Bill257: "Building Broadband Faster Act, 2021.", which received royal assent on April 12 2021[38], stating it purpose as:

  "*The purpose of the Act is to expedite the delivery of broadband projects of provincial significance by removing barriers and streamlining processes related to infrastructure that may result in delays to the timely completion of these broadband projects, while enhancing co-ordination and engagement with and being fair to public and private sector stakeholders"*

  The Act also amended Ontario Energy Board Act, enabling the Board to facilitate the efficient development of, use of and access to electricity infrastructure to which this Part applies.

  In this context, there is a great risk that the Canadian regulators (CRTC and/or OEB) may, following the precedence of the US regulator - FCC (Federal Communications Commission), take steps to bring the wireless small cells attachments to the poles under regulated framework for rate setting. For example, the FCC in its September 27, 2018, declaratory ruling (FCC 18-33) concluded that the state and local governments are limited to charge fees that are no greater than a reasonable approximation of objectively reasonable costs for processing applications and for managing deployments in the rights-of-way.

  Under such a scenario the HUG may be required to charge regulated fees, which could be significantly lower than the commercially negotiated rates.

Detailed assessment, including financial analysis of this opportunity will be provided in the commercial reports to be submitted in January 2022 for each Halton municipality. The commercial reports will also outline framework between the local municipalities and the LDCs for coordination of the operations and management of 5G small cell attachments to municipal and LDC poles.

6. Modeling 5G Benefits

We have modelled 5G use cases for different sectors of the economy as applicable to the Halton Region and its four municipalities, in order to estimate the socio-economic benefits of 5G technologies.[39] Based on a detailed economic modeling, we have estimated the potential contributions of 5G enabled services and applications across different sectors of the Halton economy as explained in the following sub-sections.

5G benefits include the following:

(a) direct benefits, i.e., increased revenues (new demand) to the 5G service providers, as well as network infrastructure providers.

(b) socio-economic benefits across different sectors of the economy in terms of increased revenues (new demand), new investments and productivity gains.

6.1 5G Direct Benefits – Telecom Services and Broadband Infrastructure Providers

The telecom services and broadband infrastructure providers are expected to generate incremental revenues with the adoption (subscriptions) of 5G services across different sectors of the economy, including consumers, businesses, government organizations. The three primary sources of 5G-related benefits include:

- **IoT Connectivity**: Incremental connectivity revenues enabled through (IoT) application across all sectors of the economy comprising:
  - *Connected Business*
  - *Connected Car*
  - *Connected Cities*
  - *Connected Consumer Electronics*
  - *Connected Energy*
  - *Connected Health*
  - *Connected Home*
  - *Connected Industry*
- **5G-enabled Applications**: Incremental revenues generated by new applications that telecom service providers will be able to offer on their 5G network, viz. **Augmented Reality** and **Ultra-HD Video**.
- **5G Migrated Subscribers:** Incremental data usage results from subscribers migrating from 4G to 5G networks and the adoption of 5G enabled services.

According to our Canadian economy survey, 5G-enabled telecom services revenues under the above three categories will increase exponentially at an annual growth rate of approximately 34%, reaching an estimated $84b over the next 10 years. In order to realize these revenues opportunities, we estimate that the telecom services and network infrastructure providers will need to invest approximately ~$11b in the next 3-5 years to deploy 5G wireless networks across Canada. We believe similar economic benefits will occur in the Region with 5G roll outs, as detailed in Section 7 below.

6.2 Long term Socio-economic benefits of 5G technologies

As noted above, 5G will enable applications - currently not possible with 4G technology, by providing the following capabilities:

- Broadband is available everywhere at speeds up to 10 Gbps.
- Smart vehicles enabled with a reliable and secure connection to the cloud.

- Super-high-definition media distribution.
- Critical control of remote devices enabled by ultra-low latency and reliability; and
- Better interaction of humans and the internet of things with support for such capabilities as tactile internet.

As illustrated in Figure 10 below, 5G will enable disruptive technologies for all economic sectors through enhanced capabilities that are not available on a wide scale in the existing 4G networks:

- ***eMBB*:** Enhanced Mobile Broadband,
- **mMTC:** Massive machine-type communications or capacity for massive machine to machine connectivity; and,
- **uRLLC:** Ultra-reliable low latency communications providing reliability to perform critical operations wirelessly.

Figure 10 below provides key examples of **uRLLC** applications, such as conducting robotic surgeries using augmented reality (AR) and virtual reality (VR) in health sector and enabling additive manufacturing using 3D printing in fully connected factories in the manufacturing sector.

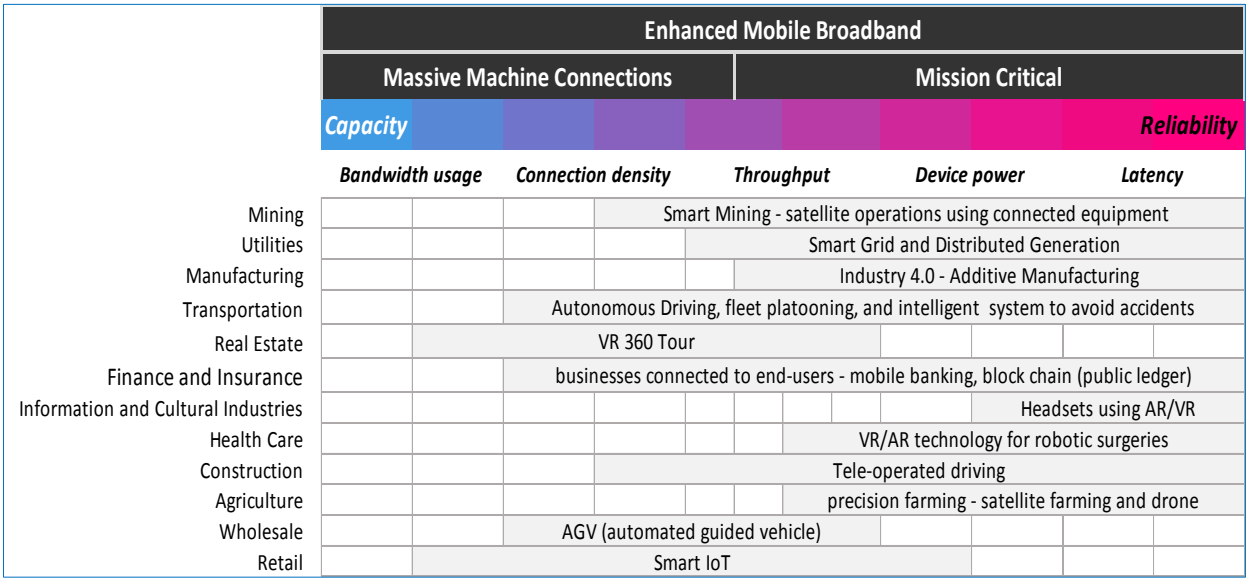


Figure 10: 5G-enabled applications

As shown in Figure 10 above, the three key applications of 5G network technologies – **eMBB, mMTC,** and **uRLLC**, are based on capacity and reliability factors (parameters) which are not available in the existing wireless networks as summarized below:

Capacity	– Very high **bandwidth density**
	– Very high **connection density**
Speed	– Very high **throughput**
Reliability	– Very low **device power** usage
	– Very low **latency**

That is 5G will be the key enabler for development of several disruptive technologies – which are needed for industry, the public sector, and the services sectors. Some of the examples of 5G Use Cases for Transport, Health, Energy & Utilities, and Manufacturing sectors are listed below.

Transport

- Autonomous Vehicles / Automated Driving
- Enhanced Road Safety and Traffic Management Services with applications such as Vehicle-to-Vehicle and Vehicle-to-Road Infrastructure (e.g., traffic lights etc.) Communication.
- Digital Transport and Logistics Systems
- Intelligent Navigation

Health

- Remote Surgery, Rehabilitation, Assisted Living Services, and Emergency Response Care Services
- Realtime Remote Health Care, Wellness Monitoring and Telemedicine
- Artificial Intelligence Based Diagnosis (Increased Accuracy)

Energy & Utilities

- Smart Grid – ability to accurately predict energy loads and system maintenance requirements
- Remote monitory of energy sites – solar/wind farm (e.g., wind conditions), power generation stations.

Manufacturing

- Additive Manufacturing or 3D Printing
- Automated Guided Vehicles (Robots, Drones, Vehicles) including Collaborative Robotics
- Augmented Reality (Remote) Maintenance, Troubleshooting, and Production Operations Management.
- Analytics to predict breakdown and downtime
- Seamless intra-/inter-enterprise communication capability to monitor facilities and installation distributed in larger area, and enable efficient coordination of cross value chain activities and optimization of process flows

Figure 11, below illustrates the relative impact of the five 5G factors in the evolution of the future **Digital Economy**, from 3G to 4G to 4G+ leading to 5G networks. It demonstrates the rapidly increasing positive impacts of low latency in generating growth in the digital economy relative to connection and bandwidth density, throughput, and device power.

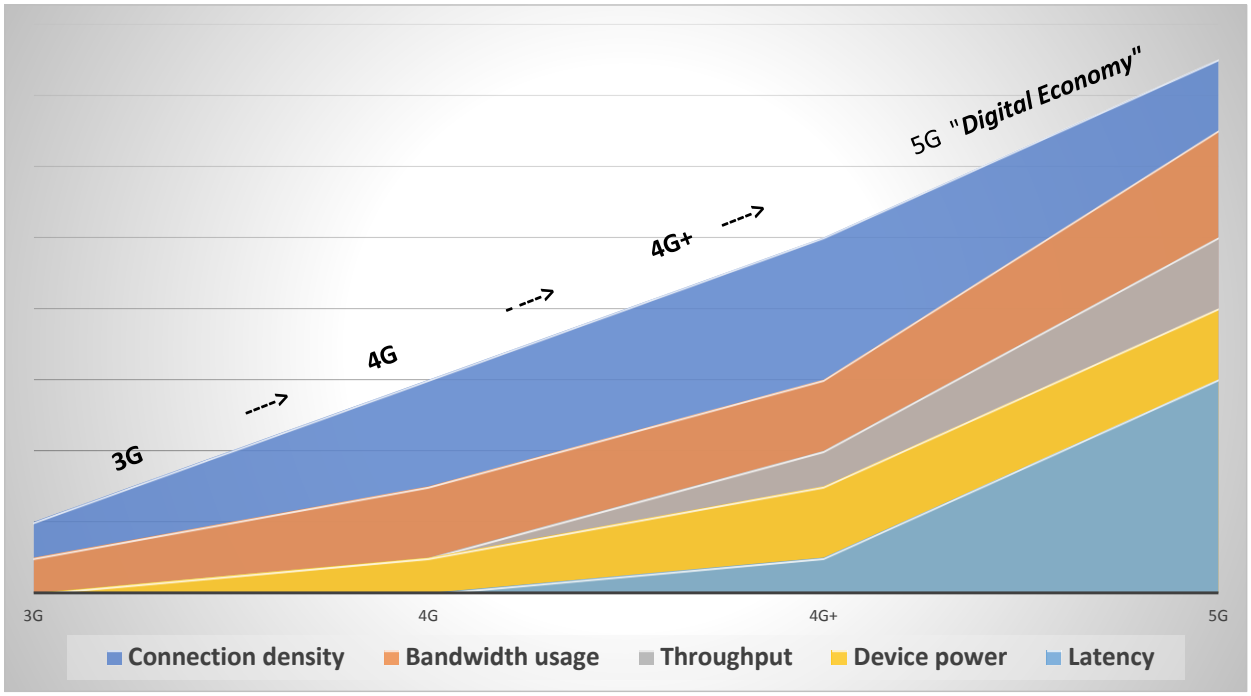


Figure 11: Impact of 5G capabilities on the evolution of the future "***Digital Economy***"

The deployment of 5G networks will have much broader impacts in the economy than previous 1G to 4G generations as ICT development and the Gigabit economy are both inextricably linked to the availability 5G networks. Thus, 5G will be the integrating force in a single infrastructure for network connectivity, information processing, and data storage - i.e., the "nervous system" of a digital economy. "***The digital economy is now firmly established as a core driver of global growth.***"[40] The next generation of digital transformation across all economic sectors will be instrumental in the evolution of the true digital economy.

5G networks will set the stage for the introduction of new technologies and applications across all sectors of the economy as illustrated in use cases provided in the next subsection.

The deployment of 5G networks will be a prerequisite to attract new investments in next-generation technologies in all sectors of the economy. By matching 5G networks and 5G technologies, economies will be able to generate new demand, efficiency, and technological enablement, resulting in long-term sustainable economic growth. We believe the **key benefit of 5G technologies will be productivity gains measured in terms of GDP growth**. However, according to our assessment, as described in Section 6.3 below, each sector's productivity gains will vary.

6.3 Modelling 5G Use Cases

Adoption and use of 5G technologies will revolutionize and transform existing economic sectors and industries. The 5G capabilities (**eMBB**-*Enhanced Mobile Bandwidth*, **mMTC**-*Massive Machine Type Communications*, and u**RLLC**-*Ultra-reliable and Low-latency Communications*) will enable applications (5G Drivers) such as ***Artificial Intelligence (AI)***, ***Cloud Computing*** and ***Internet of Things (IoT) etc.,*** as shown in Table 7 below.

Table 7: Revenue Impact of 5G Benefit Drivers

5G Benefit Driver	5G Revenue Impact*
5G Enabled Telcom Services Demand	*0.017%*
Artificial intelligence (AI)	*0.043%*
Virtual, mixed, and augmented reality	*0.013%*
Integrated Internet of Things (IoT) systems	*0.055%*
Additive manufacturing	*0.023%*
3D printing	*0.022%*
Advanced robotics	*0.013%*
Big data analytics	*0.020%*
Blockchain technologies	*0.003%*
Cloud computing	*0.364%*
Internet-connected smart devices, or Internet of things (IoT)	*0.185%*
Software and hardware using artificial intelligence (AI)	*0.381%*
***Nordicity's calculations based on StatsCan data and literature review**	

These applications will support a variety of use cases, *as explained in Appendix G*, that will drive economic resiliency in the future and increase cross-industry benefits by enabling revolutionary technical abilities. As shown in Table 7 above Cloud Computing, Internet of Things (IoT) and Artificial Intelligence will generate revenue multiplier effect to the magnitude of 0.364%, 0.185% and 0.381% respectively and hence are the major contributors to the Region's economic benefits enabled by the 5G technology. According to our estimates, 5G technologies, with its roll out starting in 2022 will generate incremental revenue of $12.4 billion in 2022-2036. Accordingly, the estimated incremental revenue will increase from $598 million in 2022 to $1,126 billion by 2026 as shown in Figure 12 below.

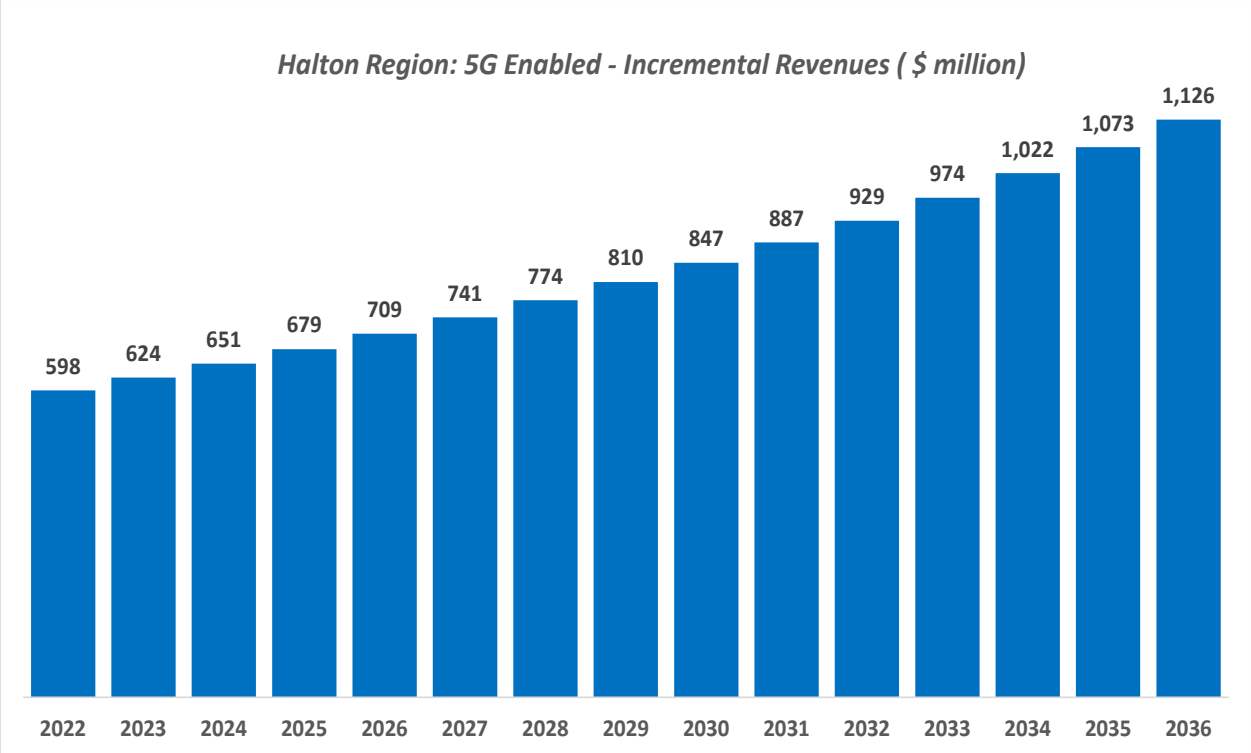


Figure 12: Projected 5G Incremental Revenue Contribution (2022-2036)
Source: Nordicity's projections based on Baseline modelling, Statistics Canada Data on emerging technology adoption rates

Over 80% of the Region's 12.4 billion revenues in 2022-2026 will enabled by the three key 5G applications including ***Artificial Intelligence***, ***Cloud Computing,*** and ***Inter-connected Smart Devices and IoTs***, as shown in Figure 9 below.

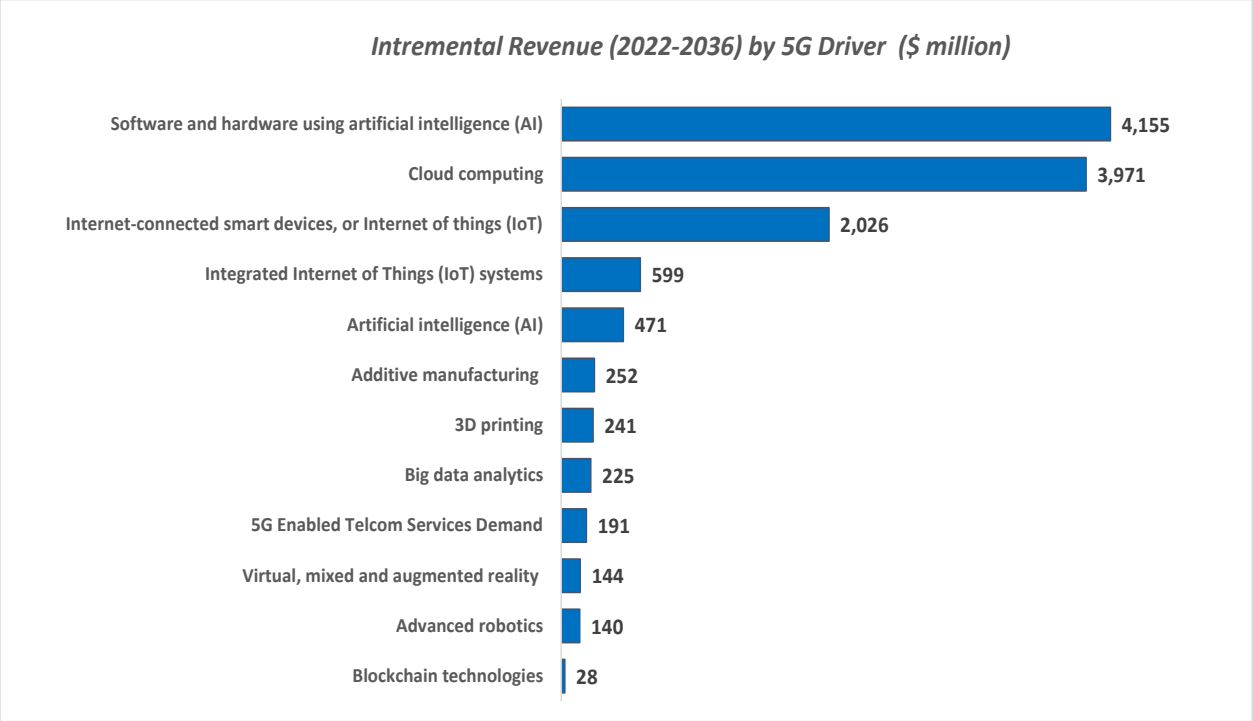


Figure 13: Cumulative impacted revenues by 5G drivers
Source: Nordicity's projections based on Baseline modelling, Statistics Canada Data on emerging technology adoption rates

7. 5G Socio-economic Impact Analysis

The present value of the $12.4 billion incremental revenue forecast is $9.66 billion - *averaging about $809 million per year or 1.65% of the existing revenues of $49 billion*. These incremental revenues (demand) will attract about $2.56 billion new investment to enable 5G applications across the 19 economic sectors of the Region. About $770 million (30%) of these investments will made by the telecommunications sector, and the remaining $1.79 billion will be invested by the business and industries across the other economic sectors of the Region. These investments represent the estimates for the development and commercialization of 5G-enabled technologies and applications across different Halton's economic sectors such as manufacturing, health care, energy, transportation and so forth.

The increased economic activities in terms of incremental revenues and new investments enabled by 5G applications in the Region will generate $12.25 billion in new GDP and will support 91,644 additional jobs in 2022-2036, as Figure 14 below. The new GDP impact will double the Region current growth trends – by additional 1.46% growth per year, representing a socio-economic return of 18.38% and a productivity gain of 1.20%.

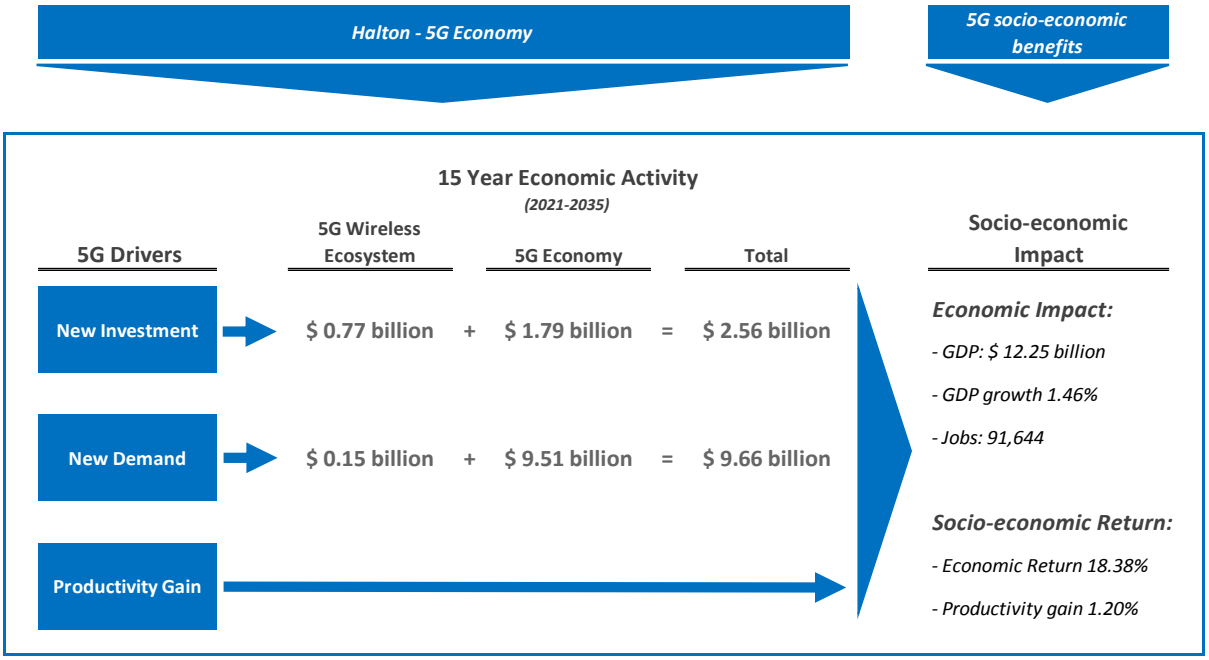


Figure 14: 5G Economic Impact Analysis Summary

Source: Nordicity's projections based on Baseline modelling, Statistics Canada Data on emerging technology adoption rates. The basis of above estimates are explained in Appendix H

As shown in Figure 15 below, the largest economic GDP impact of 5G will occur in the following five sectors of the Halton Region:

- Manufacturing ***(30% of the total impact)***
- Utilities (***15% of the total impact)***
- Real Estate Rental & Leasing ***(8% of the total impact)***
- Finance and Insurance ***(7% of the total impact)***
- Information & Cultural Industries ***(7% of the total impact)***

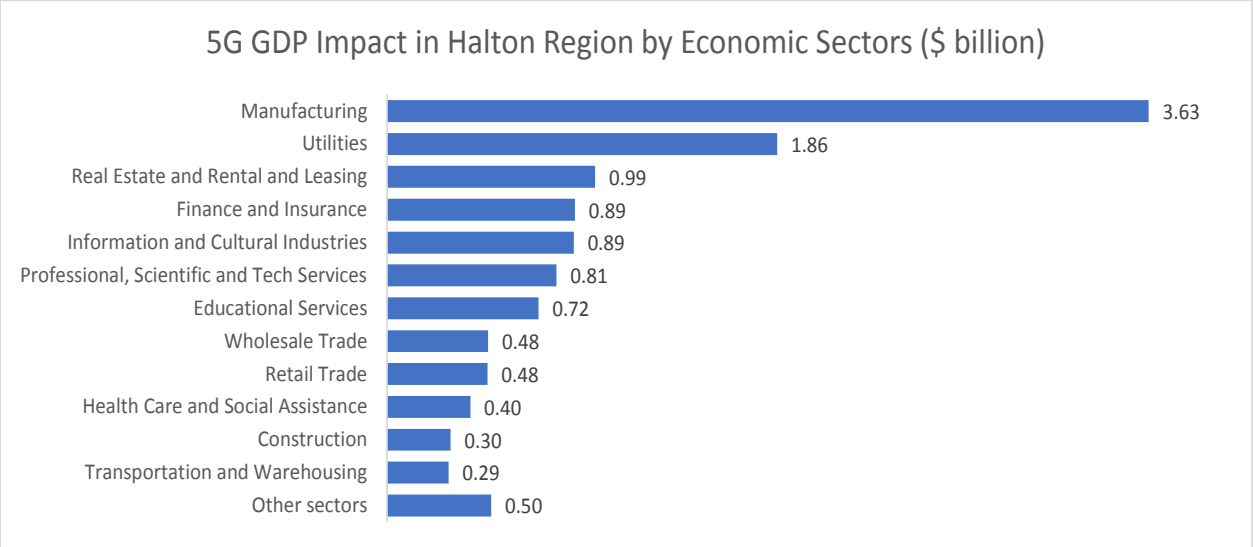


Figure 15: 5G GDP Impact in Halton Region by Economic Sectors

Source: Nordicity's projections based on Baseline modelling, Statistics Canada Data on emerging technology adoption rates

As shown in Figure 16 below, the following five sectors will lead Halton Region's 5G-driven growth in job creation.

- Manufacturing ***(27% of the total impact)***
- Utilities (***12% of the total impact)***
- Real Estate Rental & Leasing ***(8% of the total impact)***
- Education services ***(8% of the total impact)***
- Retail Trade (***7% of the total impact)***

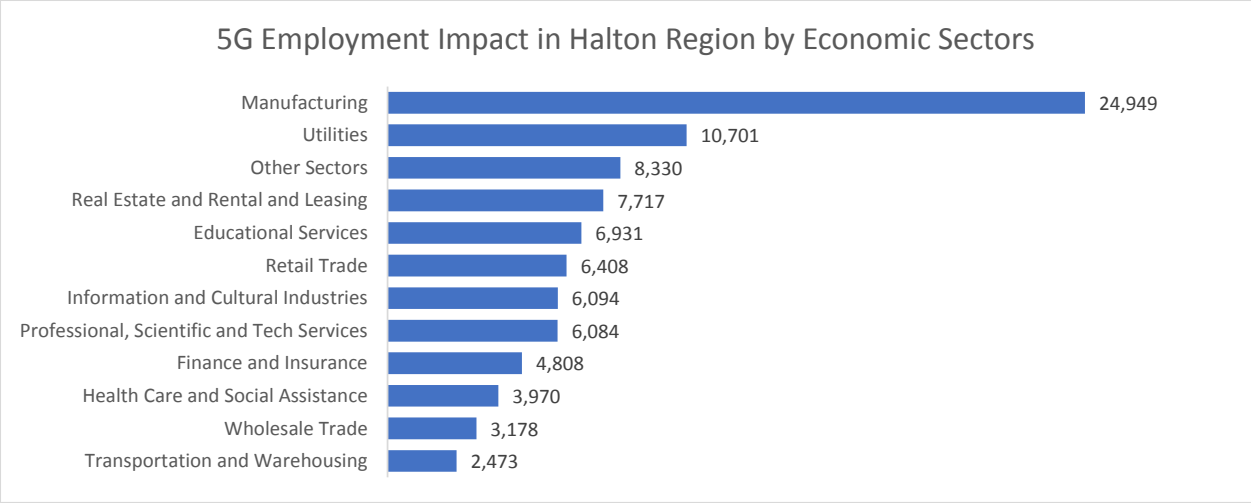


Figure 16: 5G Employment Impact in Halton Region by Economic Sectors
Source: Nordicity's projections based on Baseline modelling, Statistics Canada Data on emerging technology adoption rates

8. Recommended Digital Access Implementation Action Plan

Our analyses presented in the previous sections demonstrate that the adoption of 5G technologies will enable digital transformation across different economic sectors of the Region. The digital transformation will result significant economic benefits for the Region. The key benefits drivers include investments of $2.56 billion in new technologies, and generation of $9.66 billion of new demand, which will result in:

a) $12.25 billion GDP over the next 15 years, representing an annual GDP growth of 1.46% over and above the existing trends, and

b) productivity improvements of 1.20% representing creation of high value 91,644 jobs over the next 15 years.

8.1 FTTH/P – A Key Enabler of 5G Economic Benefits

The realization of economic benefits of 5G technologies, as explained will depend on the availability of a fully integrated wireless and wireline broadband capability across the Region, using next generation network technologies – FTTH/P (wireline), and 5G (wireless). It is worth noting that for a 5G network to deliver its promised service capabilities it is critical to provide a fiber optic connection to the 5G small cell sites. Wireless networks have limited capacity to carry data over any distance, whereas as fibre networks can carry very large size data over long distances (up to 10 kilometers) without such limitations. Furthermore, given 5G services face significant challenges in penetrating walls, foliage, etc., multiple 5G small cells are required within buildings to ensure service reliability. This means fibre connectivity will be needed into such buildings in order to provide reliable 5G services - **FTTH/P network capability across the**

Region will be a key enabler of the delivery of reliable 5G services and full realisation of the associated economic benefits.

8.2 A Unified Future Proof Broadband Capability Required

Although ISED data indicates most of the households in the Region have access to CRTC's current target speed of 50/10Mbps. However, according to our assessment about 137.5K (69%) households in the Region do not have access to internet services that meet the CRTC target (see Table 4 above). This gap may be addressed according to the two status approaches presented in sections 5.1 and 5.2 above. However, these approaches may take several years in addressing this gap given a vast majority of these households would not qualify for funding under the Federal/Provincial broadband infrastructure program. Further, both approaches will lack the integrated approach required to fully realize the economic benefits of 5G technologies across different sectors of the Region's economy.

It is worth noting that the CRTC's current speed target do not appear to align with the emerging demand for internet speed. According to our estimates over the next three to five years, the demand for internet high speed broadband services across the Region is expected to exceed the CRTC's target of 50/10 Mbps as shown in Table 8 below.[41]

Table 8: Emerging Demand Trends for Internet High Speed Services

High Speed Internet Services Demand Drivers	Expected Demand for Internet High Speed	
	3 – 5 years	Beyond 3 years
Residential (including self-employed, and work from home)	50 Mbps to 100 Mbps	100 Mbps to 1 Gbps
Small Medium Enterprises (SMEs)	50 Mbps to 1 Gbps	100 Mbps to 1 Gbps
Large Enterprises & Institutions (more than 100 employees)	100 Mbps to 10 Gbps	1 Gbps to 10 Gbps
Municipalities, Utilities, School and Health (MUSH)	100 Mbps to 10 Gbps	1 Gbps to 40 Gbps

We believe that the COVID19 pandemic has demonstrated that the emerging demand trends for internet high speed services shown above will equally apply to rural, sub-urban, and urban areas. Therefore, there is a need to address the connectivity gap on an urgent basis. One option could be to assure 50/10 Mbps in the underserved and unserved areas using FWA (Fixed Wireless Access) technology, which can be deployed relatively quickly. Under this option broadband infrastructure with 50/10 Mbps capability could be extended to the underserved and unserved areas in the Region. However, given the limitations of FWA technology we believe 50/10 Mbps would be available on a best effort basis. Furthermore, the limited ability of the FWA technology to scale up to higher speeds and the relatively small quantum of spectrum currently available for this technology, will be a limiting factor for this option. This implies that depending on the availability of spectrum and bandwidth usage trend of the internet users, future scalability to speeds higher than the 50/10 Mbps speeds under this option cannot not be guaranteed for the users. It is also worth noting that if the CRTC's target speeds are increased in the future, major upgrades of FWA network would be required in terms of deployment of additional wireless sites for capacity. This means it might be more cost efficient to consider a future proof broadband network infrastructure option, which is FTTH/P.

Since under the FTTH/P option presented in Section 5.2, the broadband networks in different parts of the Region would be deployed by different ISPs, the operational capability of the broadband networks would also depend on the different technological and network configuration choices made by the individual ISPs. Thus, quality of service and network reliability might vary as the broadband networks are deployed and

operated by different ISPs operating in the Region. On this basis we recommend the **Region proactively advocates and collaborates with the ISPs and stakeholders for an implementation of a unified broadband network in the Region using FTTH/P technology approach as explained Section 5.3. A unified FTTH/P network capability across the Region will be critical to full realization of the economic benefits of 5G technologies presented above.**

8.3 Unified Broadband Network Business Model

Future proof broadband capability in the Region will be critical to support advanced 5G applications such as smart agriculture, automated vehicles, home-based medical consultations and diagnostics, advanced manufacturing – Industry 4.0. These applications will require a reliable and scalable broadband capability to support large scale deployment of IoTs including but not limited to smart homes, buildings, offices, connected vehicles etc. Therefore, we believe it would be more cost efficient to consider a future proof broadband network infrastructure option. Accordingly, we recommend implementation of a unified broadband network across the Region using 100% FTTH/P technology. Under this approach, the broadband infrastructure would be operated by a single entity, to deliver broadband services on a wholesale basis using an open access framework.

The broadband infrastructure may be jointly owned and/or operated by a group of private sector players (as in case of Durham Broadband) such as investors, ISPs, etc.

We believe this option would future proof the Region's broadband infrastructure capability in terms of meeting the exponentially increasing demand for internet speed and broadband usage in emerging digital economy world. The unified broadband service would be scalable up to and beyond 1 Gbps as required and ensure service reliability and redundancy. Open access to the network would encourage competing service providers to offer a range of affordable services to different subscribers' groups across the Region.

The analysis shown in Table 5 above indicates that it might be more cost efficient to implement a uniform future proof broadband infrastructure across the region, which will permanently address the internet connectivity challenges in the Region. Furthermore, this option will help eliminate the digital-divide and enable equitable realization of the socio-economic benefits of 5G technologies by all the residents in the Region.

The unified broadband service would be scalable up to and beyond 1 Gbps as required and ensure service reliability and redundancy. We also believe there is need for an open access regime to prevent deployment of duplicate networks by different ISPs. An open access regime would encourage competing service providers to offer a range of innovative and affordable services to different subscribers' groups across the Region. Therefore, we recommend the Region undertakes initiatives to encourage deployment of a unified broadband network by the ISPs.

9. Conclusion

We believe the Region can play an instrumental role in adoption of 5G technologies leading to the evolution of 1Gig+ economy. This study demonstrates that the 5G technology will have a transformative effect on employment, productivity, and GDP in the different economic sectors of the Region. For example, according to our estimates the adoption of 5G technologies will significantly increase the digital sector share, create higher value jobs (productivity improvement), doubling its annual GDP growth, which currently trends at 1.40%. However, the realization of these benefits will depend on the availability of reliable and scalable high-speed internet services - which is not only critical to meet the

emerging demand for high-speed internet connectivity but also for the enablement of digital infrastructure in the Region to ensure its long term sustainable economic development.

It is worth noting that in the 5G world, wireless network would represent a small portion of the massive capacity required for data traffic generated by a large-scale deployment of IoTs including but not limited to smart homes, buildings, offices, connected vehicles etc. This means the 5G promise is heavily predicated on the deployment of future proof wireline broadband network technology which is FTTH/P.

Based on our estimates almost 90% of the households currently do not have access to internet services with speeds of 50/10 Mbps or more, using future proof (FTTH/P) fixed broadband. This means a significant gap exists in most parts of the Region in terms of broadband capability in meeting the emerging demands for reliable and scalable highspeed services in a digital (1Gig+) economy

To fill this gap, we recommend implementation of a unified broadband network in the Region using FTTH/P technology to deliver broadband services which may be based on an open access framework. We believe a unified FTTH/P network capability across the Region will be critical to the full realization of the economic benefits of 5G technologies as presented in this study.

Furthermore, the ISPs would require about $362.8 million investment to deploy FTTH/P network in the unserved/underserved areas of the Region. This investment represents 82% of the total $439.5 million to deploy a future proof FTTH/P network across the entire Region. This means it will make more sense for the ISPs to deploy a unified future proof FTTH/P network in the Region, with an additional investment of $76.7 million.

The unified broadband service would be scalable up to and beyond 1 Gbps as required and ensure service reliability and redundancy. We also believe there is need for an open access regime to prevent deployment of duplicate networks by different ISPs. An open access regime would encourage competing service providers to offer a range of innovative and affordable services to different subscribers' groups across the Region. Therefore, we recommend the Region undertakes initiatives to encourage deployment of a unified broadband network by the ISPs.

Appendix A: GDP Mix – Halton Region Municipalities

Economic Sectors	Burlington - Total					
	2016	2017	2018	2019	2020	Growth
Manufacturing	$1.80B	$1.83B	$1.75B	$1.84B	$1.69B	-1.60%
Wholesale trade	$0.57B	$0.58B	$0.51B	$0.43B	$0.42B	-7.43%
Retail trade	$0.62B	$0.65B	$0.66B	$0.64B	$0.73B	4.32%
Transport and Warehousing	$0.31B	$0.32B	$0.29B	$0.29B	$0.19B	-11.03%
Information and cultural industries	$0.43B	$0.45B	$0.54B	$0.46B	$0.51B	4.33%
Finance and insurance	$0.66B	$0.75B	$0.65B	$0.71B	$0.79B	4.67%
Management of companies and enterprises	$0.20B	$0.19B	$0.21B	$0.16B	$0.10B	-16.25%
Professional, scientific and technical services	$0.74B	$0.74B	$0.72B	$0.80B	$0.79B	1.79%
Administrative and support, waste management and remediation services	$0.16B	$0.17B	$0.16B	$0.16B	$0.13B	-4.68%
Education services	$0.66B	$0.68B	$0.70B	$0.60B	$0.60B	-2.13%
Arts, entertainment and recreation	$0.09B	$0.10B	$0.12B	$0.12B	$0.07B	-5.59%
Accommodation and food services	$0.21B	$0.22B	$0.22B	$0.24B	$0.17B	-5.71%
Other Services	$0.27B	$0.28B	$0.27B	$0.29B	$0.25B	-1.23%
Remaining sectors	$2.48B	$2.36B	$2.46B	$2.57B	$2.64B	1.60%
Total	**$9.20B**	**$9.32B**	**$9.26B**	**$9.30B**	**$9.11B**	**-0.26%**

Note: Growth rate above is compound annual growth rate

Economic Sectors	Oakville- Total					
	2016	2017	2018	2019	2020	Growth
Manufacturing	$1.65B	$1.48B	$1.43B	$1.54B	$1.38B	-4.47%
Wholesale trade	$0.42B	$0.45B	$0.44B	$0.46B	$0.45B	1.74%
Retail trade	$0.53B	$0.57B	$0.57B	$0.57B	$0.61B	3.47%
Transport and Warehousing	$0.33B	$0.34B	$0.32B	$0.28B	$0.20B	-11.05%
Information and cultural industries	$0.33B	$0.30B	$0.33B	$0.35B	$0.35B	1.37%
Finance and insurance	$0.88B	$0.98B	$0.92B	$1.09B	$1.26B	9.19%
Management of companies and enterprises	$0.32B	$0.30B	$0.27B	$0.18B	$0.11B	-23.25%
Professional, scientific and technical services	$0.94B	$0.94B	$0.99B	$1.05B	$0.95B	0.18%
Administrative and support, waste management and remediation services	$0.09B	$0.12B	$0.10B	$0.11B	$0.09B	1.34%
Education services	$0.64B	$0.75B	$0.72B	$0.76B	$0.74B	3.59%
Arts, entertainment and recreation	$0.15B	$0.15B	$0.16B	$0.18B	$0.10B	-9.84%
Accommodation and food services	$0.20B	$0.21B	$0.21B	$0.20B	$0.15B	-7.54%
Other Services	$0.24B	$0.26B	$0.25B	$0.27B	$0.25B	0.68%
Remaining sectors	$2.53B	$2.71B	$2.95B	$3.36B	$3.80B	10.75%
Total	**$9.26B**	**$9.57B**	**$9.65B**	**$10.39B**	**$10.44B**	**3.03%**

Note: Growth rate above is compound annual growth rate

Economic Sectors	Milton - Total					
	2016	2017	2018	2019	2020	Growth
Manufacturing	$0.54B	$0.51B	$0.52B	$0.66B	$0.53B	-0.58%
Wholesale trade	$0.43B	$0.52B	$0.43B	$0.47B	$0.43B	-0.06%
Retail trade	$0.20B	$0.21B	$0.22B	$0.24B	$0.24B	4.25%
Transport and Warehousing	$0.25B	$0.25B	$0.23B	$0.26B	$0.19B	-6.89%
Information and cultural industries	$0.04B	$0.04B	$0.05B	$0.05B	$0.05B	4.71%
Finance and insurance	$0.12B	$0.13B	$0.11B	$0.11B	$0.11B	-1.77%
Management of companies and enterprises	$0.01B	$0.01B	$0.01B	$0.01B	$0.00B	-20.50%
Professional, scientific and technical services	$0.12B	$0.12B	$0.13B	$0.19B	$0.15B	6.23%
Administrative and support, waste management and remediation services	$0.05B	$0.06B	$0.05B	$0.08B	$0.06B	3.08%
Education services	$0.27B	$0.29B	$0.28B	$0.29B	$0.26B	-0.59%
Arts, entertainment and recreation	$0.11B	$0.10B	$0.10B	$0.11B	$0.05B	-16.08%
Accommodation and food services	$0.08B	$0.08B	$0.08B	$0.09B	$0.07B	-2.61%
Other Services	$0.08B	$0.09B	$0.10B	$0.12B	$0.11B	8.29%
Remaining sectors	$1.06B	$1.17B	$1.28B	$1.37B	$1.47B	8.41%
Total	$3.36B	$3.58B	$3.57B	$4.02B	$3.72B	2.56%

Note: Growth rate above is compound annual growth rate

Economic Sectors	Halton Hills - Total					
	2016	2017	2018	2019	2020	Growth
Manufacturing	$0.49B	$0.50B	$0.51B	$0.61B	$0.48B	-0.48%
Wholesale trade	$0.05B	$0.05B	$0.05B	$0.05B	$0.05B	1.43%
Retail trade	$0.22B	$0.23B	$0.24B	$0.26B	$0.27B	4.70%
Transport and Warehousing	$0.11B	$0.12B	$0.14B	$0.17B	$0.10B	-2.61%
Information and cultural industries	$0.13B	$0.12B	$0.13B	$0.13B	$0.10B	-6.80%
Finance and insurance	$0.06B	$0.06B	$0.07B	$0.07B	$0.07B	6.04%
Management of companies and enterprises	$0.01B	$0.01B	$0.01B	$0.01B	$0.00B	-20.00%
Professional, scientific and technical services	$0.07B	$0.06B	$0.06B	$0.08B	$0.07B	-0.60%
Administrative and support, waste management and remediation services	$0.01B	$0.01B	$0.02B	$0.02B	$0.01B	3.23%
Education services	$0.13B	$0.13B	$0.13B	$0.13B	$0.12B	-1.61%
Arts, entertainment and recreation	$0.05B	$0.05B	$0.05B	$0.05B	$0.03B	-9.66%
Accommodation and food services	$0.05B	$0.05B	$0.05B	$0.05B	$0.04B	-7.84%
Other Services	$0.06B	$0.06B	$0.06B	$0.06B	$0.06B	0.18%
Remaining sectors	$0.77B	$0.79B	$0.79B	$0.78B	$0.82B	1.87%
Total	$2.20B	$2.25B	$2.29B	$2.47B	$2.23B	0.29%

Note: Growth rate above is compound annual growth rate

Appendix B: Halton's Digital Economy (GDP)

As part of this analysis, we estimated the current digital share in the GDP of the Halton Region and four municipalities. The Digital share represents the economic value of digital economic activities in the region. For this purpose, we leveraged StatsCan's recently published Digital Supply-Use framework, which captures and presents the digital and non-digital components of the production by domestic industries, imports of products, and their use, either as inputs for final consumption, investment, and exports.

As shown in Figure 17 below, the Halton Region's digital sector generated GDP of $2.22 billion in 2016, which increased to $2.37 billion in 2020, representing a compound annual average growth rate (CAGR) of 1.67%. While the *"direct"* contribution constituted a major proportion of the total impact, the inter-sectoral linkages captured in *"indirect"* impact reflect a lower but evolving contribution towards the digital sector's growth. The accelerated spread of COVID-19 in 2020 uncovered and intensified numerous operational constraints in every economic sector globally. The pandemic also affected the digital economy sectors in both positive and negative ways. Negative effects include the shut down of some of the ICT goods manufacturing units, which formed a key component of digital economy and globalized supply chain, roadblocks posed by travel restrictions, and finally, lack of spending by consumers in early COVID phase adversely affected some digital industries. However, these adverse effects were more than offset by a boom in ***e-commerce***, ***"telecommunications (broadband connectivity"***, ***"software"***, and the other digital economy verticals, which ensured a growth rate of the sector in 2020.

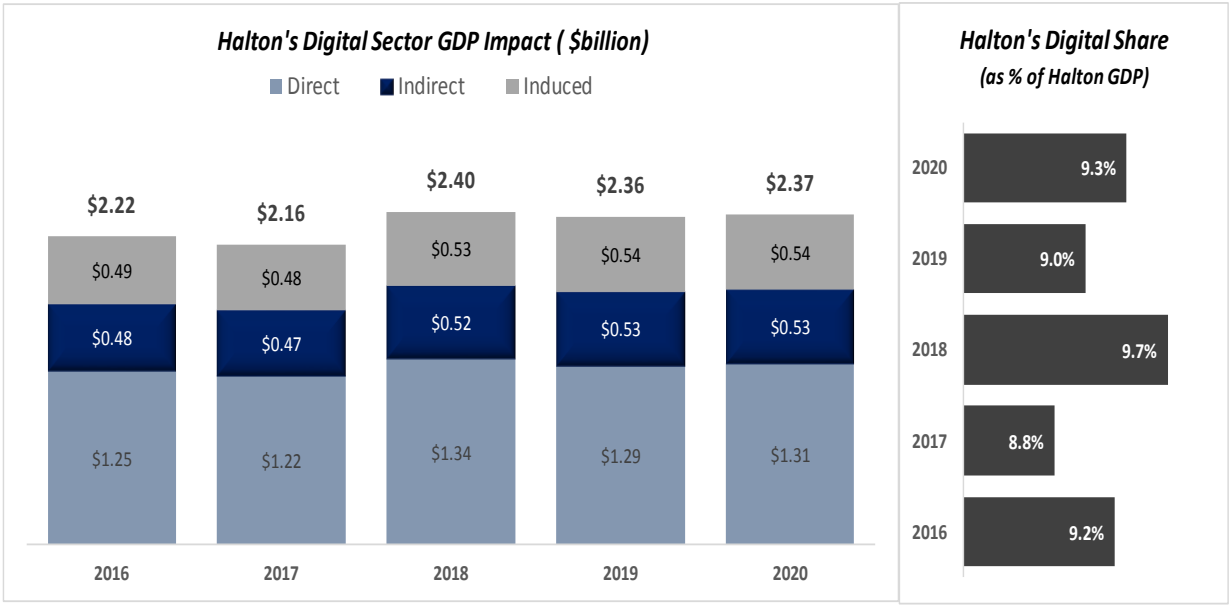


Figure 17: Digital Sector GDP Impact (Direct + Indirect + Induced) & Digital Economy Share

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables.

Note: The above estimates were developed based on the methodology outlined in Appendix C.

The digital sector is considered to be a catalyst of economic growth and hence its contribution in terms of share in national economy reflects upon the sector's strength in driving the Halton region's GDP growth. As shown in

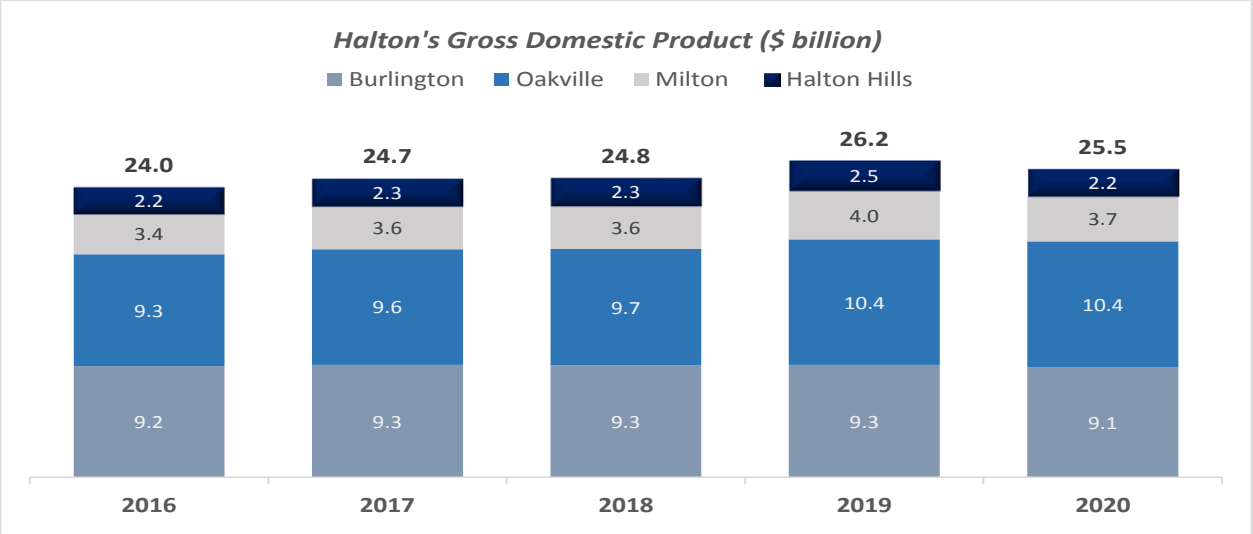


Figure 4, Halton's overall GDP (nominal) increased from $24.0 billion in 2016 to $25.5 billion in 2020, representing a compound annual growth rate of 1.40 % (using GDP at current prices). Because of higher growth in GDP driven by Halton's digital sector, its contribution (share) in its overall GDP increased from 9.2% in 2016 to 9.3% in 2020, as shown in **Error! Reference source not found.** below.

Figure 18 below presents the Halton region's GDP broken out by the four municipalities: Burlington, Oakville, Milton, and Halton Hills.

- **Burlington:** Digital GDP grew at a compound annual rate of 2.42% from $1.16 billion (2016) to $1.27 billion (2020).
- **Oakville:** the digital sector grew at 2.19%(CAGR) from $761 million (2016) to $830 million (2020).
- **Milton:** the digital sector GDP increased from $99 million (2016) to $105 million in 2020 at 1.54%.
- **Halton Hills:** the digital sector contributed $204 million of value-add (GDP) in 2016; however, it declined in subsequent years to $147 million in 2020.

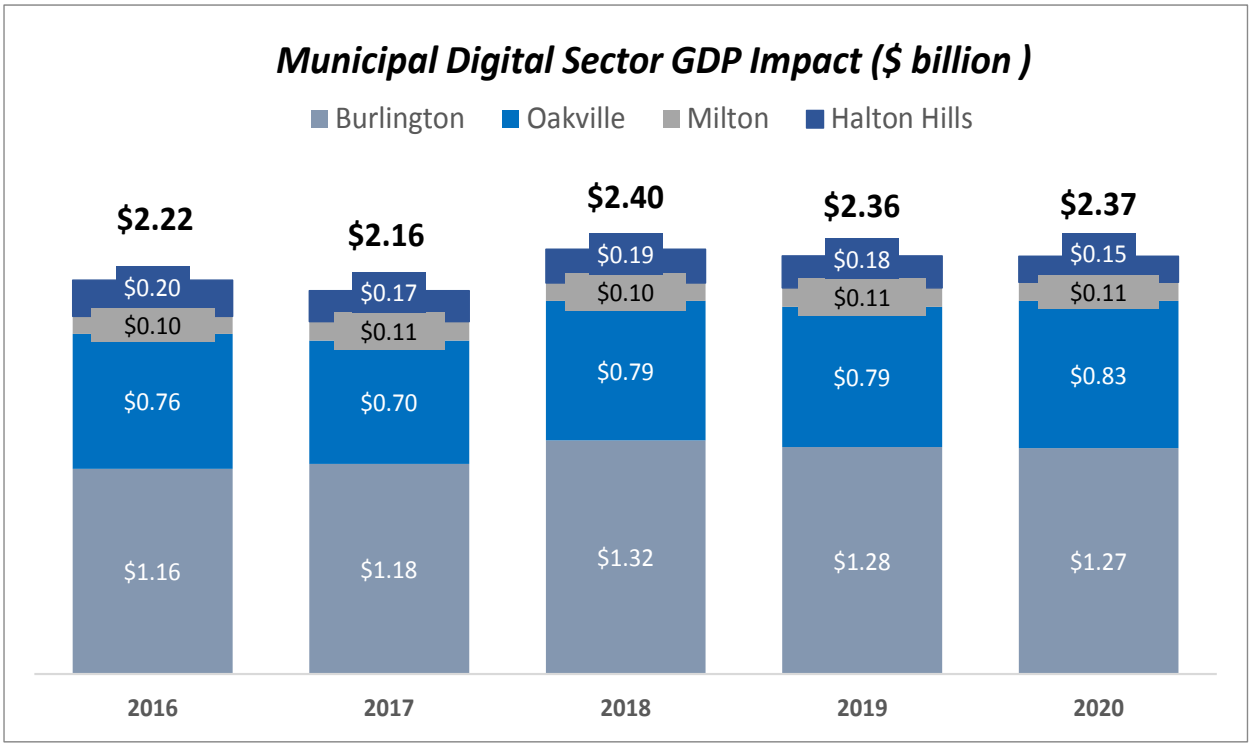


Figure 18: Municipal Digital Sector GDP Impact (Direct + Indirect + Induced)

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables

Halton Region Digital Sector GDP Mix

To better understand the economic trends that steered the performance of Digital Sector in 2016-2020, the total Digital GDP component was broken down by verticals. The contribution of each vertical to the Halton's digital economy (GDP) is described in Figure 19 below.

Halton Region, a prominent manufacturing centre in North America, boasts of a rich innovation ecosystem focused on advanced manufacturing firms in automotive, steel, and materials. in addition, Halton's manufacturing base supports the technology clusters (ICT, cleantech, fintech, e-commerce, etc.) thriving in the region.

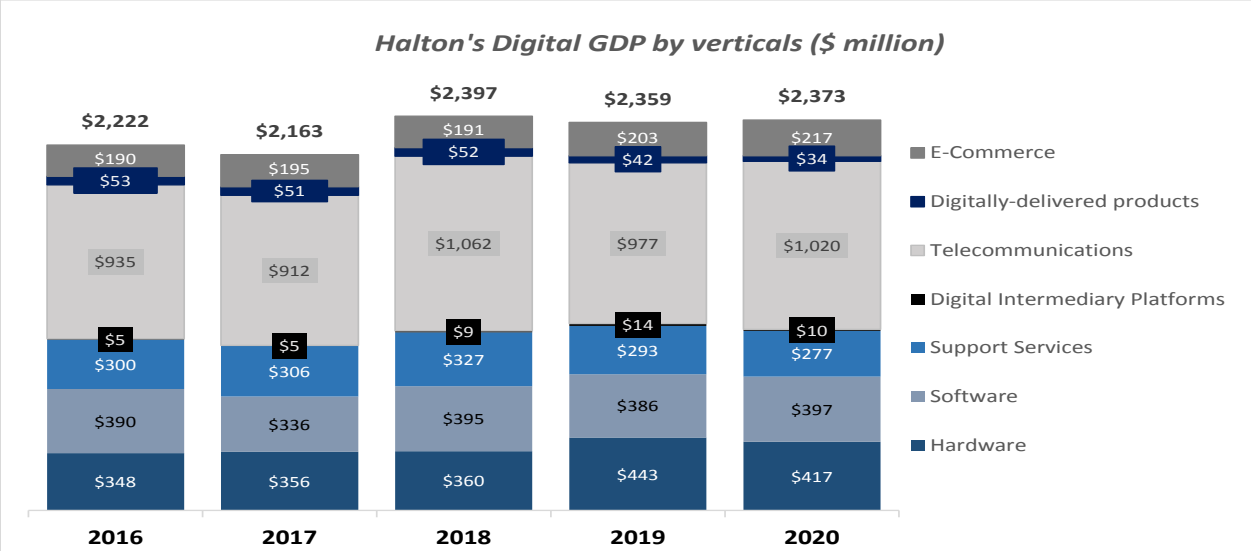


Figure 19: Halton's Digital Sector GDP Impact (Direct + Indirect + Induced) by verticals/ sub-sectors

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables.

Note: A detailed account of Digital GDP impact by verticals for the four municipalities is presented in Appendix D.

The hardware segment/ICT manufacturing of Halton's Digital economy remained robust during 2016-2020 with its total contribution to Halton's GDP increasing from $348 million (2016) to $417 million (2020). This performance occurred despite the worldwide shut down of manufacturing units and supply chain disruptions which adversely impacting production and trade of hardware or ICT goods.

The shutdown of manufacturing units in the east Asia – the world's ICT manufacturing hub, in 2020, triggered an increase in component prices by 2-3% due to shortage of supplies [42]. This surge in input prices also caused the increase in the prices of finished hardware goods, further accentuated by a fall in production of ICT hardware, including computer, communication, and electronic equipment/components. However, despite this global slowdown, Halton's Digital hardware sector registered 4.6% growth (CAGR) in 2016- 2020.

A major portion of this growth was driven by Burlington, which contributed $353 million in 2020 to the hardware sector, exhibiting a growth of 3.3% (CAGR) from its contribution in 2016 ($310 million). Oakville was second to Burlington with a $64 million contribution to GDP in 2020. Milton & Halton Hills both had positive but small contributions to Halton's Digital hardware GDP in 2016 ($1.1 million, and $696 thousand, respectively), however, these were reduced substantially (by over 60%) in 2020 ($6K & $15K)

The software development segment of Halton's Digital Economy contributed $397 million to Total Digital GDP in 2020 exhibiting a growth of 0.5% CAGR from 2016 ($390 million). Oakville led the development of software services in 2016 ($202 million) and remained the top contributor in 2020 with a total GDP impact of $197 million. Burlington's contribution to Halton's software segment exhibited a steady growth of 5.25% (CAGR), increasing from $142 million (2016) to $174 million in 2020. Milton's software segment showed a steady increase in its GDP contribution from $11.7 million in 2016 to $14 million in 2020 whereas Halton Hill's contribution declined from $34.8 million in 2016 to $12.1 million in 2020.

Support Services contribution to digital GDP declined by 2% in Halton region. A similar downward trend was observed in Burlington, Halton Hills, and Milton where the support services GDP contribution declined by 4.6% 7.1% and 14.8%, respectively. Oakville emerged as an exception with an increase in support services GDP: from $107 million in 2016 to $123 million in 2020, exhibiting a growth rate of 3.4% CAGR.

Telecoms also emerged as a resilient sector in the Halton Region amidst the economic downturn triggered by the spread of Covid 19. While the demand for telecommunication services took a hit from its business customers due to derailment of sectors like travel, tourism & hospitality, and closure of businesses, households have seen a surge in demand. Mandatory work from home and streaming as the safest means of entertainment, have strengthened the demand for broadband services. As a result, the GDP contribution of telecommunications sector increased from $935 million in 2016 to $1020 million 2020, exhibiting a compound annual growth rate of 2.2%. In 2016-2020, the growth of the telecom sector in Milton and Burlington were among the highest with 4.6% and 4.2 % respectively. Oakville exhibited a modest growth of 1.3% during the same period. Halton Hills, however, experienced decline in the telecom sector with its contribution decreasing from $130 million in 2016 to $97.8 million in 2020.

Digitally delivered products included in the analysis were products created and delivered (either to intermediaries or final consumers) in digital format by finance & insurance industries and arts & entertainment and recreation sectors - including gambling industries. While digital financial services witnessed a growth in its contribution to GDP, the non-depository credit intermediation services, entertainment, and gambling industry have experienced steady decline in the region during 2016 -2020. As a result, the contribution of this vertical to Halton's digital economy declined from $53 million (2016) to $34 million (2020). The rate of decline was greater in 2020, possibly because the arts & entertainment sector took a huge hit during the peak of Covid crisis. A similar trend was observed in other municipalities, where the contribution of digitally delivered products declined in all years during 2016-2020.

Finally, Halton region's e-commerce and digital intermediary services sub-sectors exhibited substantial growth during 2016-2020. While e-commerce grew at a compound annual growth rate of 3.4 %, the digital intermediary services exhibited substantial growth of 21.2% (CAGR) during 2016-2020. The peer-to-peer services intermediated by digital intermediary platforms such as Airbnb, Uber, etc. facilitate transactions in goods and services. These platforms have become increasing popular and have witnessed exponential growth in last few years. In 2020, Burlington and Oakville contributed $3 million each in Digital Intermediary platforms followed by Milton ($2.3 million) and Halton Hills ($1.2 million). All four municipalities registered over 15% growth in this subs-sector during 2016-2020.

Appendix C: Halton Region Digital Sector Employment

In 2016 the Halton Digital sector employed 16,216 FTE (Full Time Equivalent) employees, referred to as "employment", which increased to 16,384, a modest average increase of 0.26% per year as shown in Figure 20. As a result, the share of digital employment in Halton's over all economy remained the same at around 7.2% during the study period.

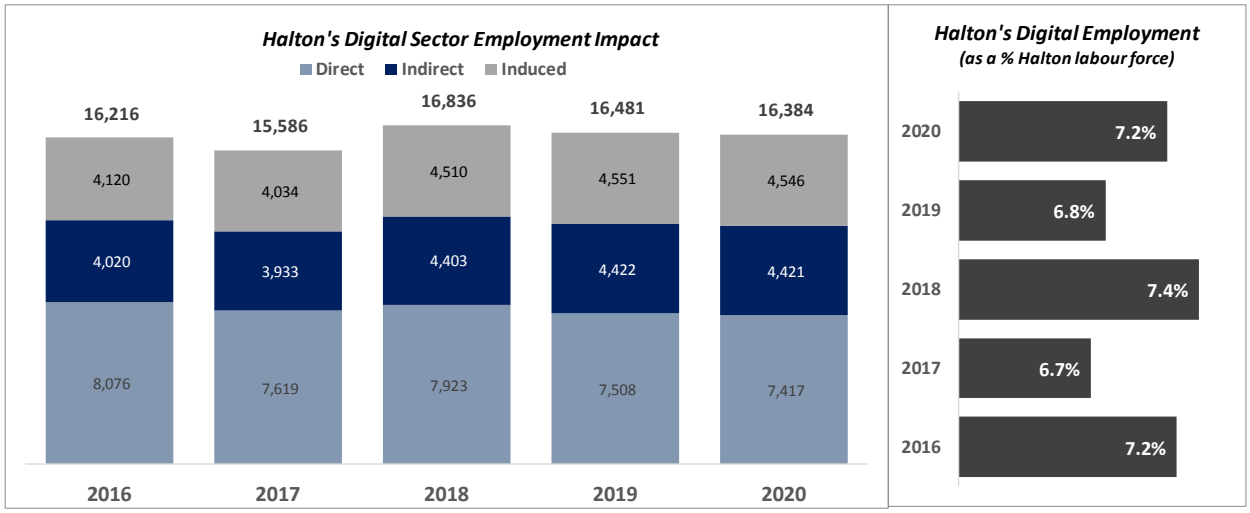


Figure 20: Halton's Digital Sector Employment Impact (Direct + Indirect + Induced) & Digital Share

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables

As shown in Figure 21, Burlington with an average 55% share in Halton's employment impact, exhibited a modest growth of 0.84% by increasing from 8,599 FTEs in 2016 to 8,890 FTEs in 2020.

Following a similar growth trend, Oakville's FTEs increased from 5,535 in 2016 to 5,757 in 2020, constituting on an average 34% of Halton's employment impact. Whereas Milton and Halton Hills constituted about 4% and 7% of Halton's Employment impact, respectively.

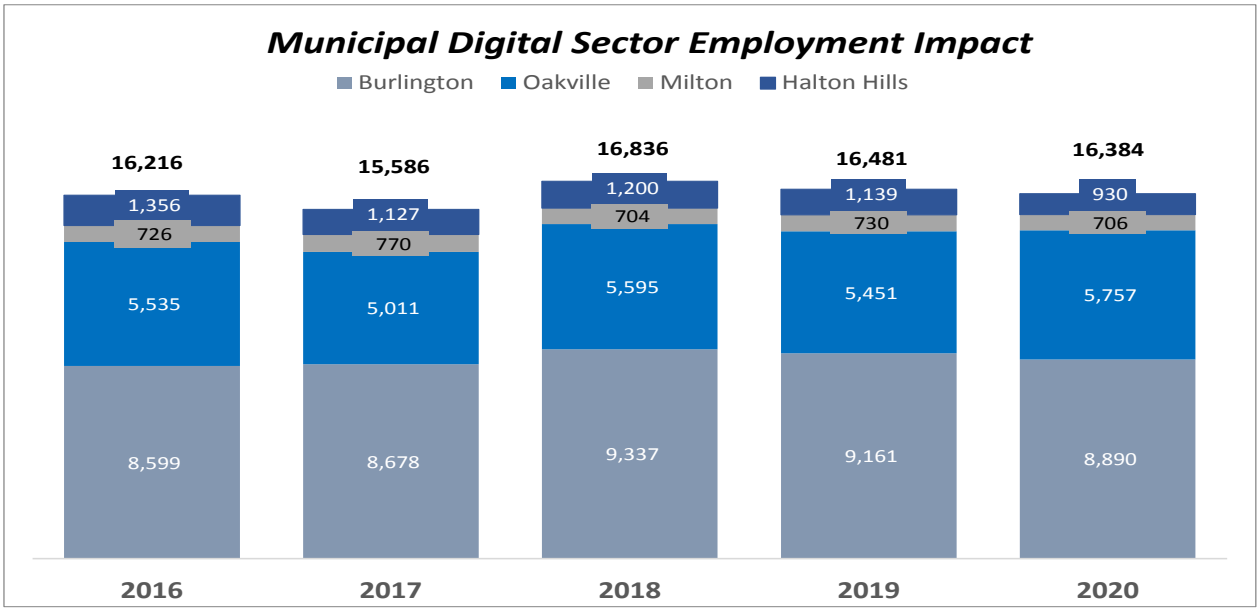


Figure 21: Municipal Digital Sector Employment Impact (Direct + Indirect + Induced)

Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada & Digital Supply -Use Tables

Halton Region Digital Sector Employment Mix

Halton's ICT sector employment impact by vertical/sub-sector is shown in Figure 22 below. Telecommunications, Software, and Hardware have been major contributors to employment to Halton's Digital sector. While the share of digitally delivered products and support services declined during 2016-2020, the share of e-commerce exhibited a modest growth of 1.1% during the same year. Digital Intermediary platforms, yet again emerged as a vertical/sub-sector with the highest growth potential with a compound annual growth rate of 15.2%.

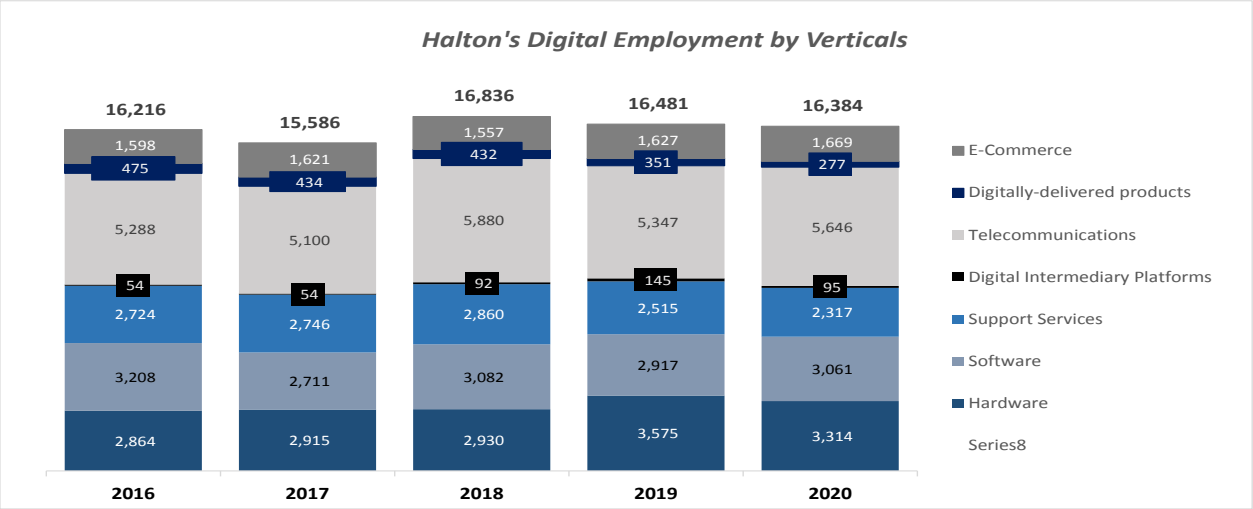


Figure 22: Halton's Digital Sector Employment Impact (Direct + Indirect + Induced) by verticals/sub-sectors

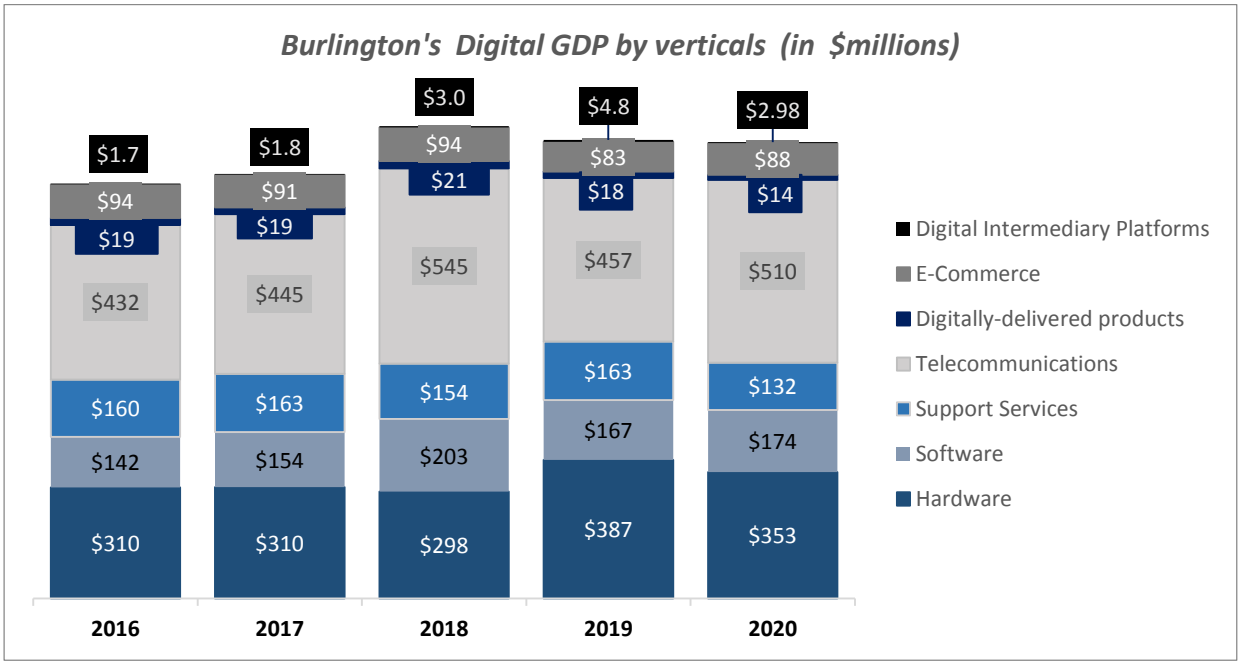
Source: Nordicity's calculations based on Halton Employment Survey, Statistics Canada Data & Digital Supply -Use Tables

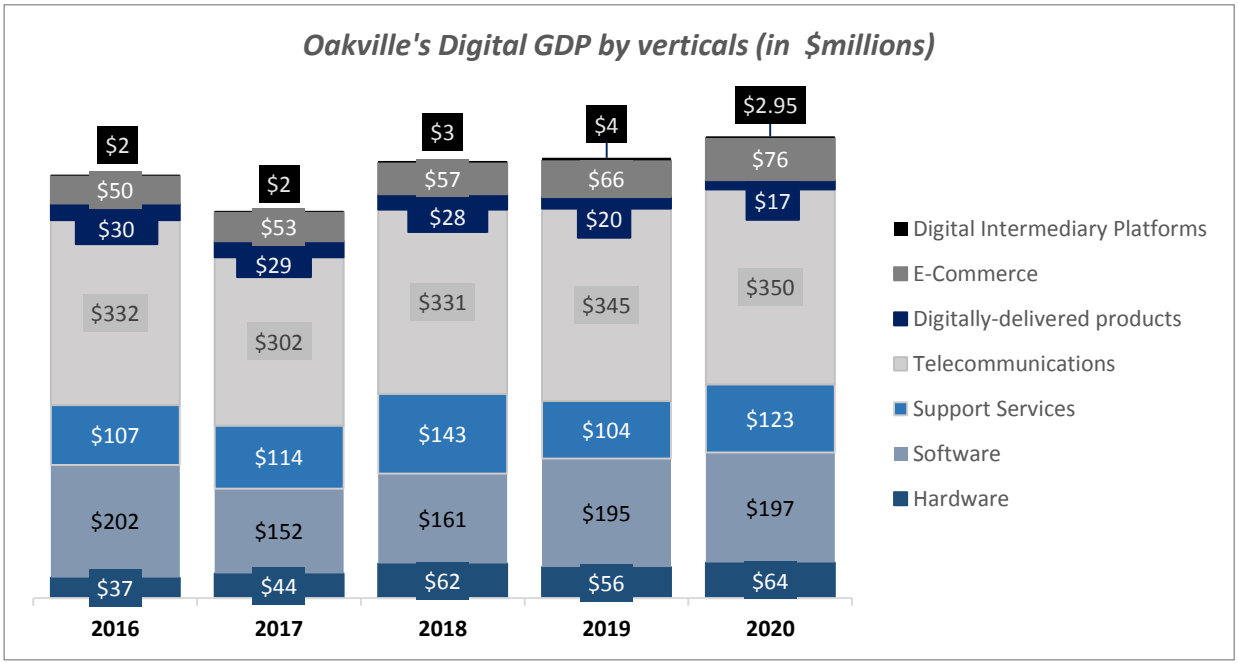
A detailed account of Digital Employment impact by verticals for the four municipalities are presented in Appendix E.

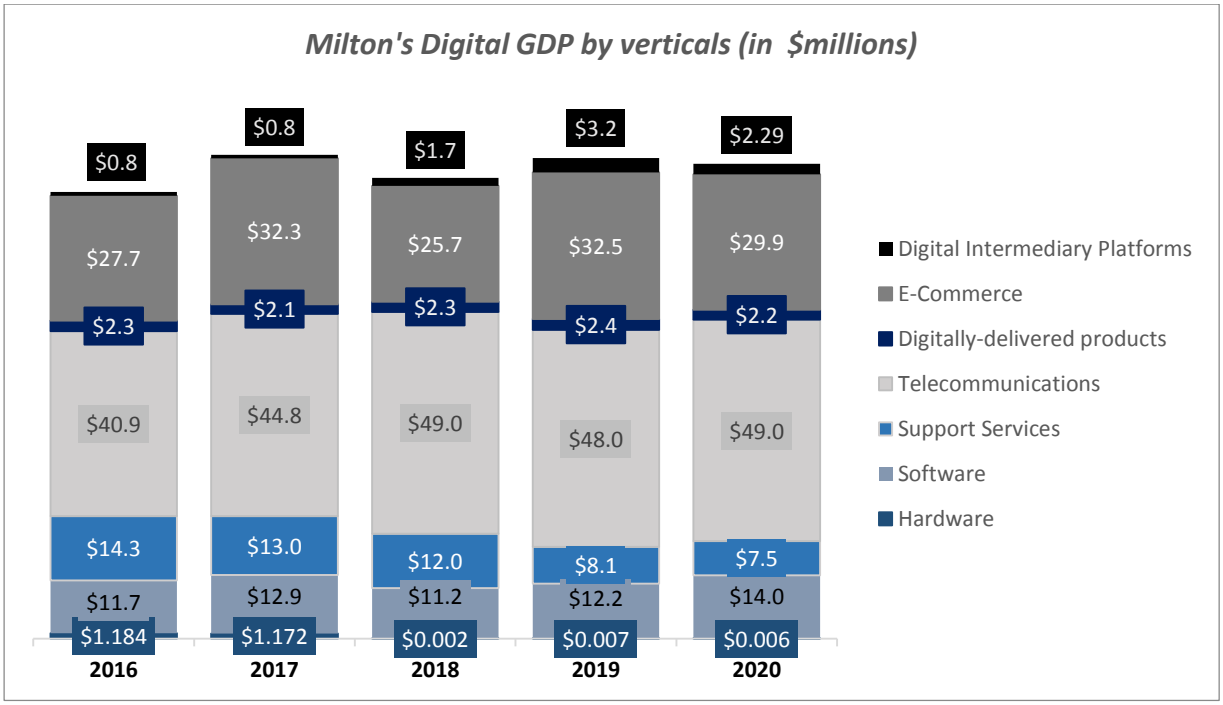
Of the four municipalities, Burlington contributed most towards employment in the hardware sub-sector, constituting an average share of 86% at a compound annual growth rate of 2.42%. Burlington also registered positive employment growth in the Software (3.57%) and Telecommunications (3.69%) sub-sectors. While Oakville exhibited substantial compound annual growth in its Hardware (13.9%), E-commerce (9%) and Digital Intermediary Platforms (9%) sub-sectors, in Milton growth occurred in Software (3.05%), Telecommunication (4.07%), and Digital Intermediary Platform (24.82%) sub-sectors of its digital economy.

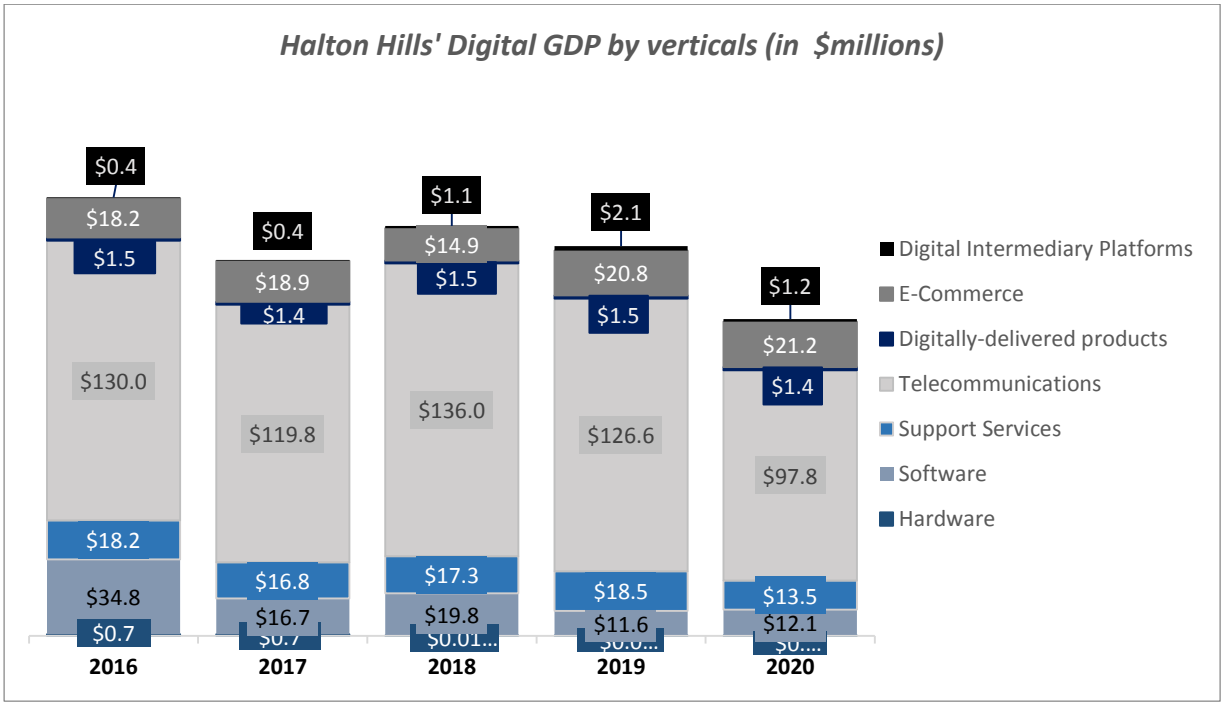
Finally, for Halton Hills, E-commerce and Digital intermediary platforms were the sub-sectors with a positive annual growth of 1.2% and 27.9%. The steep decline in employment for some sub-sectors like hardware in Milton & Halton Hills could be the result of the economic meltdown caused by Covid Crisis. The prolonged lockdown in the region could have caused temporary & even permanent shutdowns of specific businesses leading to decline in employment in these sub-sectors.

Appendix D: GDP Impact by Verticals

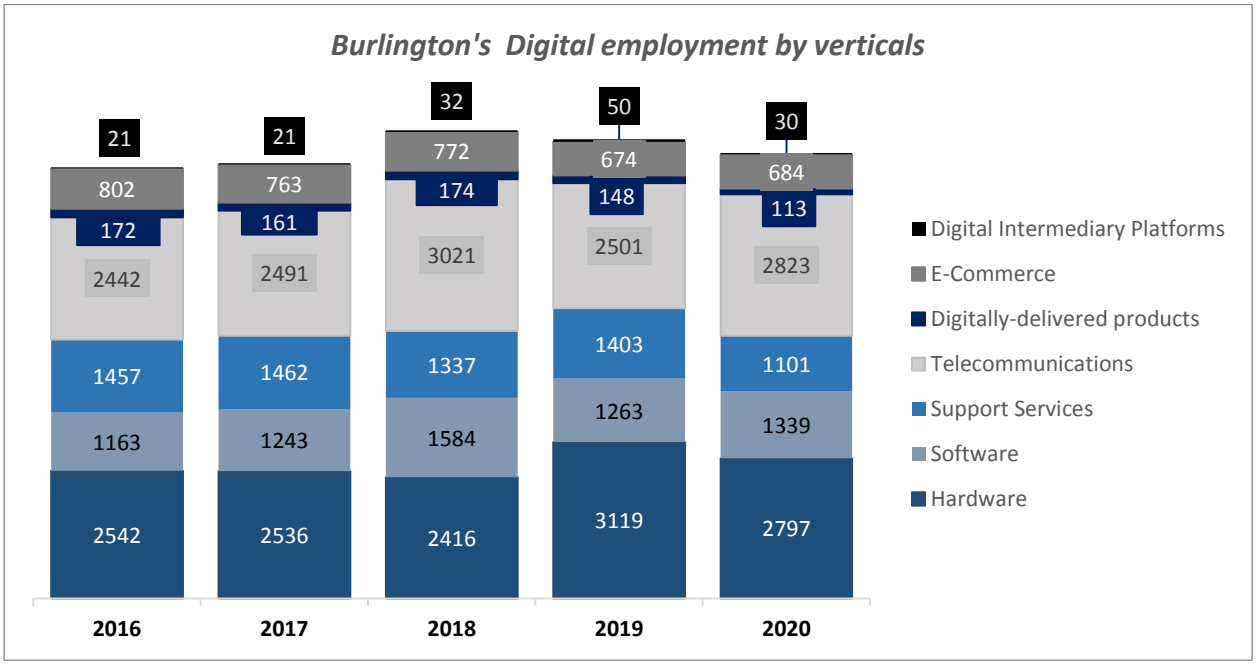


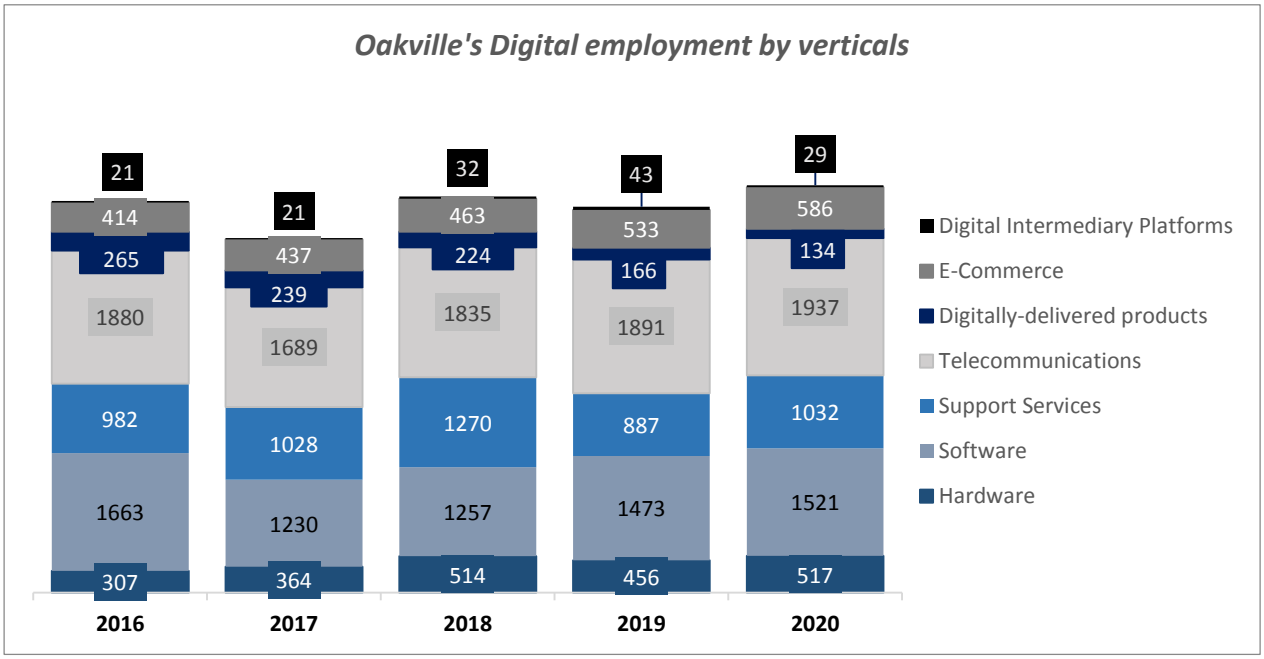


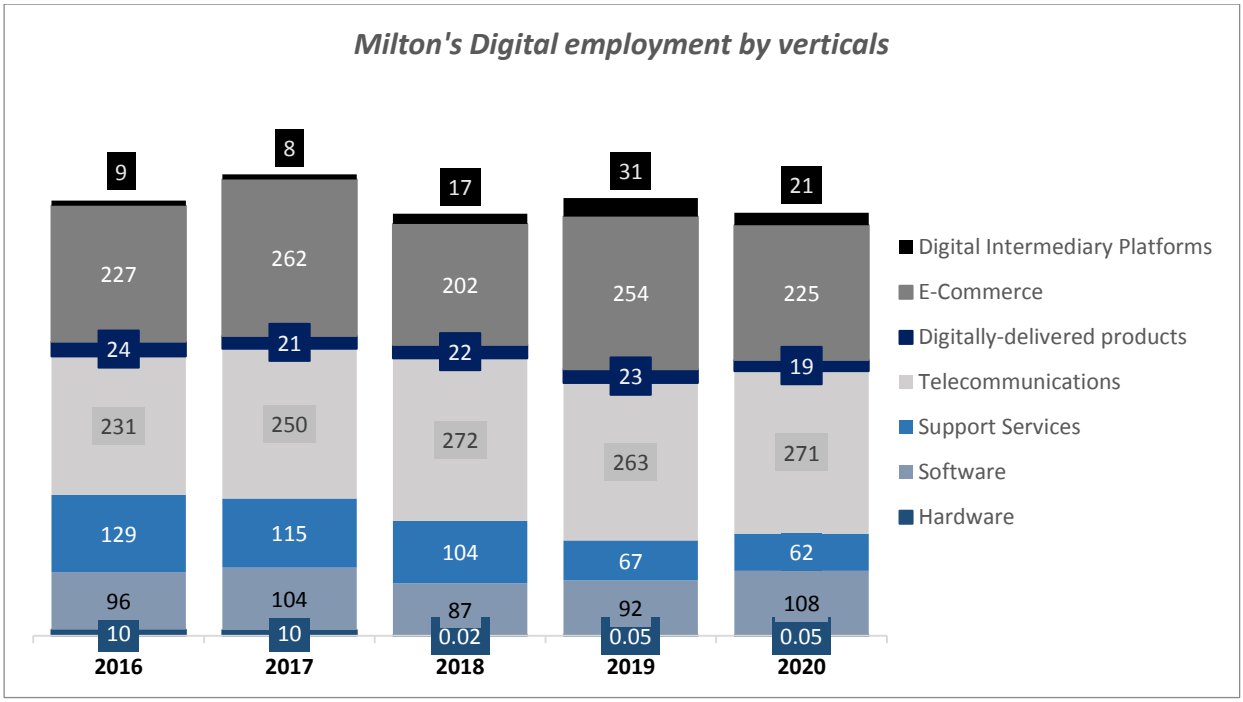

Milton's Digital GDP by verticals (in $millions)
$0.8
$0.8
$1.7
$3.2
$2.29
$27.7
$32.3
$25.7
$32.5
$29.9
$2.3
$2.1
$2.3
$2.4
$2.2
$40.9
$44.8
$49.0
$48.0
$49.0
$14.3
$13.0
$12.0
$8.1
$7.5
$11.7
$12.9
$11.2
$12.2
$14.0
$1.184
$1.172
$0.002
$0.007
$0.006
2016
2017
2018
2019
2020
Digital Intermediary Platforms
E-Commerce
Digitally-delivered products
Telecommunications
Support Services
Software
Hardware

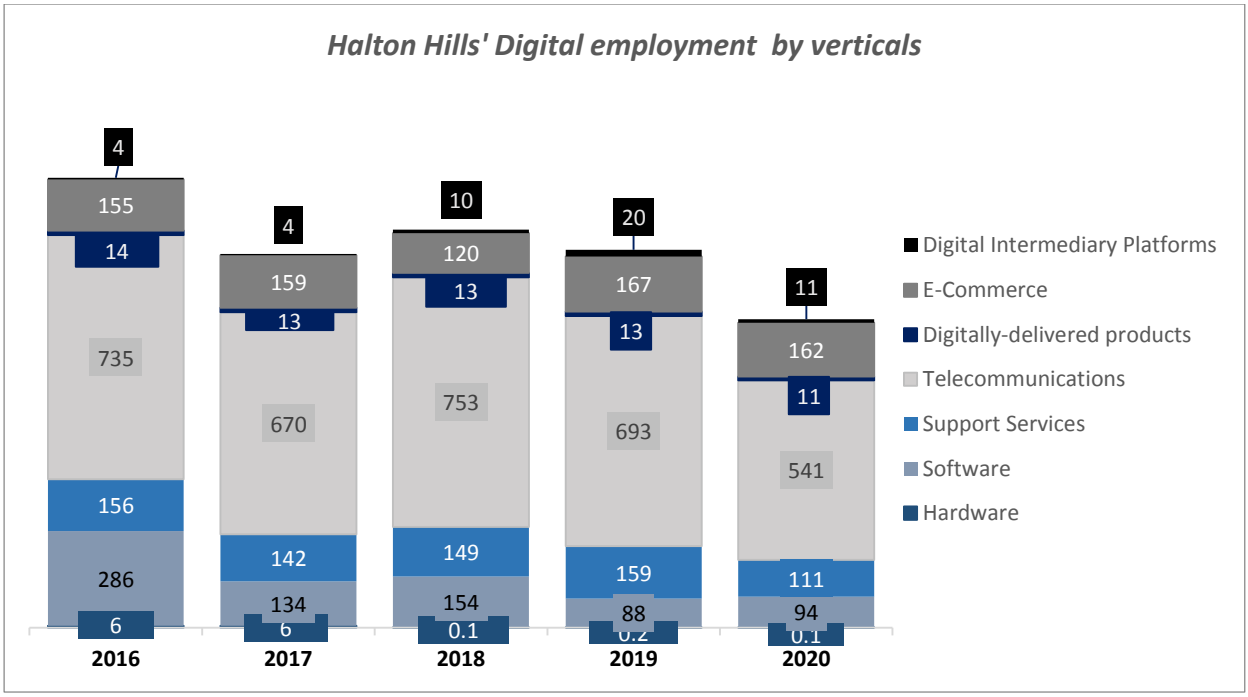

Halton Hills' Digital GDP by verticals (in $millions)
$0.4
$0.4
$1.1
$2.1
$1.2
$18.2
$18.9
$14.9
$20.8
$21.2
$1.5
$1.4
$1.5
$1.5
$1.4
$130.0
$119.8
$136.0
$126.6
$97.8
$18.2
$16.8
$17.3
$18.5
$13.5
$34.8
$16.7
$19.8
$11.6
$12.1
$0.7
2016
2017
2018
2019
2020
Digital Intermediary Platforms
E-Commerce
Digitally-delivered products
Telecommunications
Support Services
Software
Hardware

Appendix E: Employment Impact by Verticals

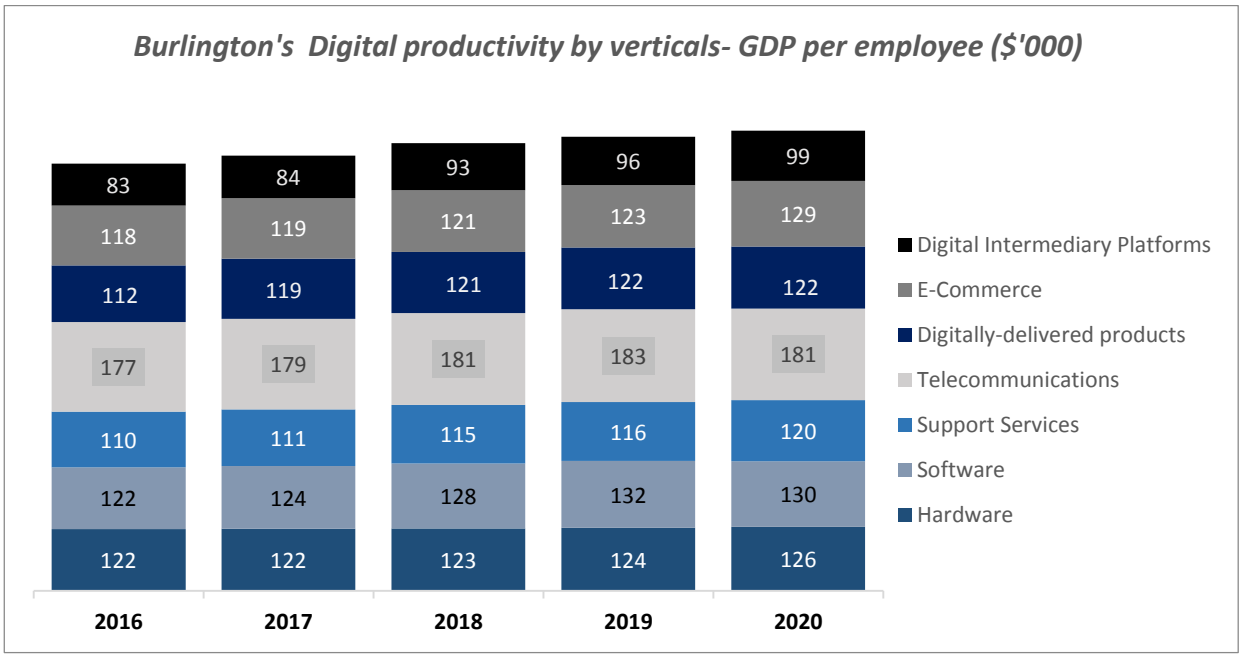


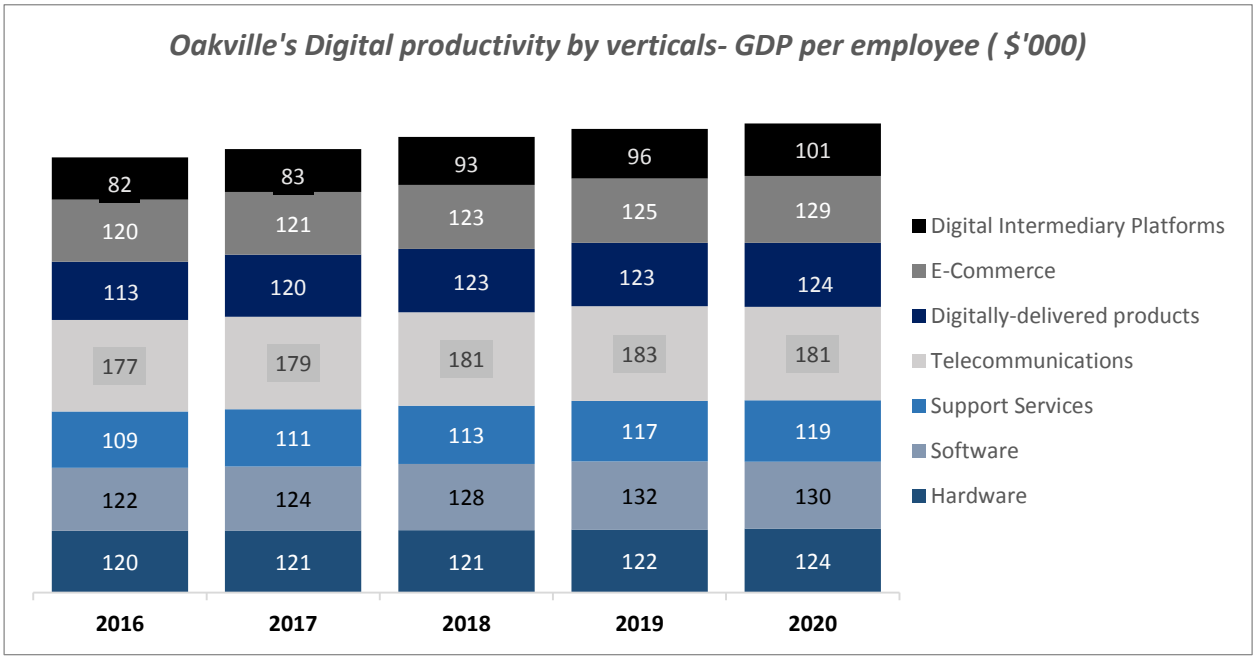


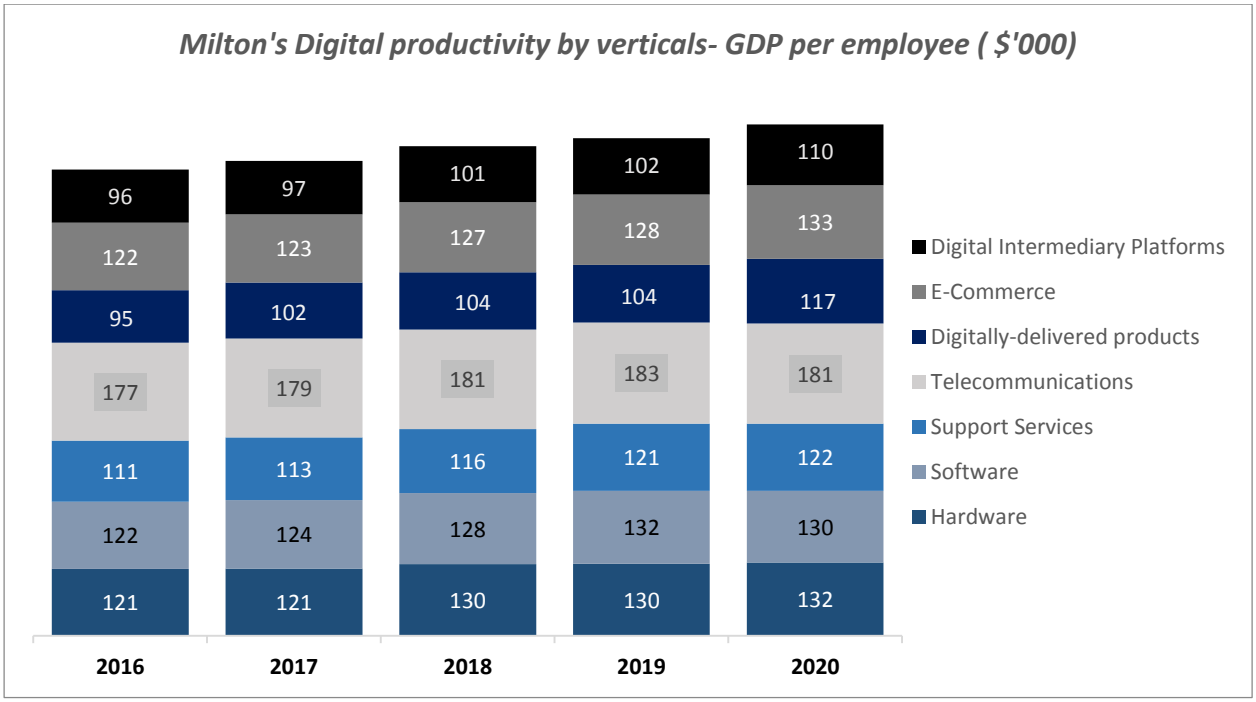

Milton's Digital employment by verticals
9
8
17
31
21
227
262
202
254
225
24
21
22
23
19
231
250
272
263
271
129
115
104
67
62
96
104
87
92
108
10
10
0.02
0.05
0.05
2016
2017
2018
2019
2020
Digital Intermediary Platforms
E-Commerce
Digitally-delivered products
Telecommunications
Support Services
Software
Hardware

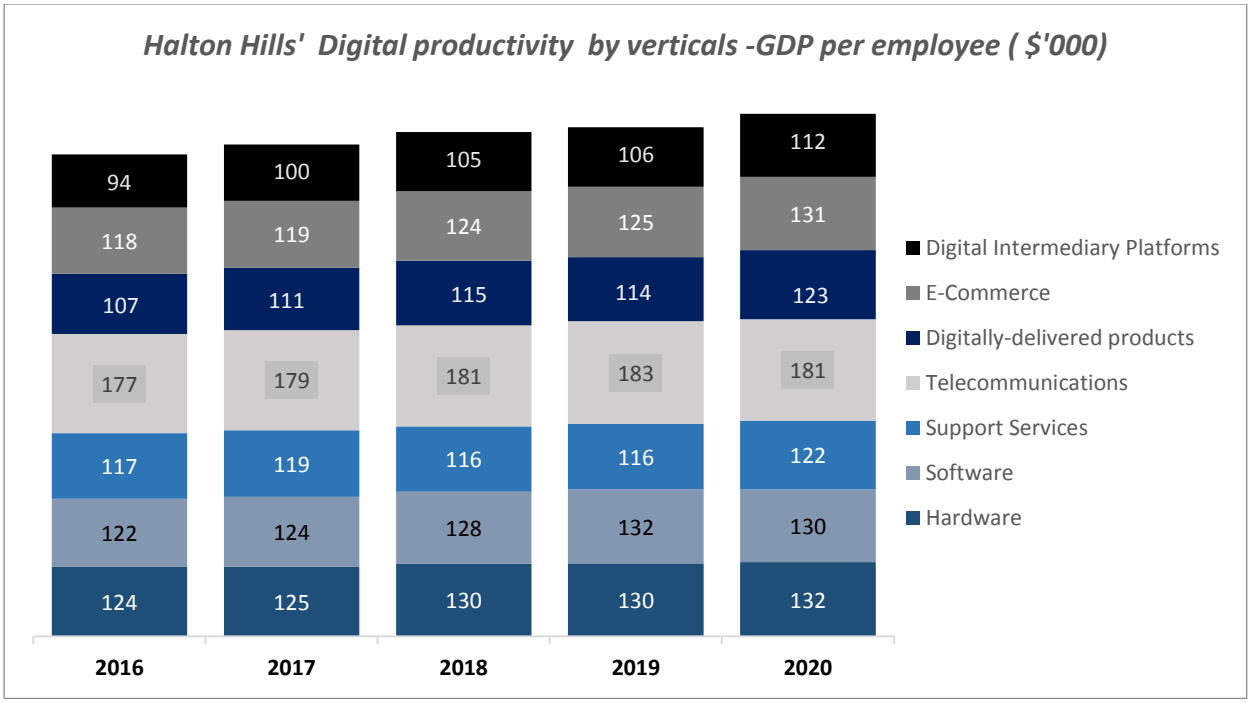

Halton Hills' Digital employment by verticals
4
4
10
20
11
155
159
120
167
162
14
13
13
13
11
735
670
753
693
541
156
142
149
159
111
286
134
154
88
94
6
6
0.1
0.2
0.1
2016
2017
2018
2019
2020
Digital Intermediary Platforms
E-Commerce
Digitally-delivered products
Telecommunications
Support Services
Software
Hardware

Appendix F: Productivity Impact by Verticals






Milton's Digital productivity by verticals- GDP per employee ($'000)
96
122
95
177
111
122
121
97
123
102
179
113
124
121
101
127
104
181
116
128
130
102
128
104
183
121
132
130
110
133
117
181
122
130
132
2016
2017
2018
2019
2020
Digital Intermediary Platforms
E-Commerce
Digitally-delivered products
Telecommunications
Support Services
Software
Hardware


Halton Hills' Digital productivity by verticals -GDP per employee ($'000)
94
118
107
177
117
122
124
100
119
111
179
119
124
125
105
124
115
181
116
128
130
106
125
114
183
116
132
130
112
131
123
181
122
130
132
2016
2017
2018
2019
2020
Digital Intermediary Platforms
E-Commerce
Digitally-delivered products
Telecommunications
Support Services
Software
Hardware

Appendix G: 5G Use Cases by Sector

To understand the magnitude and timing of the economic impact 5G adoption and use, we analyzed the following 19 economic sectors of Halton Region and its municipalities.

a) Accommodation and Food Services
b) Admin. & Support, Waste Management Services
c) Agriculture, Forestry, Fishing and Hunting
d) Arts, Entertainment and Recreation
e) Construction
f) Educational Services
g) Finance and Insurance
h) Health Care and Social Assistance
i) Information and Cultural Industries
j) Manufacturing
k) Mining, Quarrying, and Oil and Gas Extraction
l) Other Services (except Public Administration)
m) Professional, Scientific and Technical Services
n) Public Administration
o) Real Estate and Rental and Leasing
p) Retail Trade
q) Transportation and Warehousing
r) Utilities
s) Wholesale Trade

We modelled the impact of 5G applications (***5G benefit drivers***) to demonstrate their economic impact on the 19 economic sectors in terms of GDP, jobs and productivity improvements.

Adoption and use of 5G technologies will revolutionize and transform existing economic sectors and industries. The 5G capabilities including eMBB-*Enhanced Mobile Bandwidth*, mMTC-*Massive Machine Type Communications*, and uRLLC-*Ultra-reliable and Low-latency Communications* will enable applications that will drive productivity improvement and new demand for products and services resulting in new (incremental) revenue (demand) streams in the above listed 19 economic sectors. The 5G applications their estimated impact on new revenues generation in the Region's economy are shown in Table 7 in Section 6.3 above.

These applications will support a variety of use cases that will drive economic growth in the future and increase cross-industry benefits by enabling revolutionary technical abilities. For example, as shown in Table 7 the Artificial Intelligence, Cloud Computing, and Internet of Things (IoT) will generate revenue multiplier effect to the magnitude of 0.364%, 0.185% and 0.381% respectively and hence will be the major contributors of the economic benefits in the Region's 19 economic sectors. For these sectors about $12.4 billion new revenues are estimated in the next 15 years, representing $598 million with 5G initial rollout in 2022 (assumed), increasing at rate of 4.6% per year to $1.26 billion by 2036, as shown in Figure 12 in Section 6.3 above. Top three 5G applications that will account for over 80% of the forecasted 12.4 billion revenues include ***Artificial Intelligence (34%)***, ***Cloud Computing (32%)*** and ***Inter-connected Smart Devices and IoTs (16%)***, as shown Figure 13 in Section 6.3 above.

In 2020 total revenues generated in the Region by the 19 economic sectors are estimated to be $48.95 billion, manufacturing being the largest with is share of 30.7% ($15.03 billion), followed by Real Estate 8.3% ($4.03 billion), and others as shown in Table 9 below.

Table 9: Halton 2020 Revenues Mix by 19 Key Economic Sectors

Halton's Key Economic Sector	Current Sales (2020)	
	Amount *($ billion)*	**Share**
Manufacturing	15.03	30.7%
Real Estate and Rental and Leasing	4.08	8.3%
Finance and Insurance	4.01	8.2%
Retail Trade	3.19	6.5%
Professional, Scientific and Technical Services	2.97	6.1%
Health Care and Social Assistance	2.70	5.5%
Educational Services	2.42	4.9%
Wholesale Trade	2.31	4.7%
Public Administration	2.07	4.2%
Information and Cultural Industries	1.93	3.9%
Construction	1.82	3.7%
Transportation and Warehousing	1.61	3.3%
Utilities	1.24	2.5%
Other Services (except Public Administration)	1.13	2.3%
Accommodation and Food Services	0.96	2.0%
Arts, Entertainment and Recreation	0.53	1.1%
Admin. & Support, Waste Management Services	0.52	1.1%
Agriculture, Forestry, Fishing and Hunting	0.35	0.7%
Mining, Quarrying, and Oil and Gas Extraction	0.08	0.2%
Total	**48.95**	**100.0%**

The $12.4 billion incremental revenue estimated to be enabled by 5G application, represent an annualised average of $809 million per year (representing a compound growth rate of 1.65%) to the $48.95 billion revenues currently generated by the businesses in the Region.

While all 19 sectors in the Region will benefit from the 5G applications, the greatest impacts (over 2% annual increase in revenues) will occur in certain sectors such as *Utilities*, *Information and Cultural Industries*, *Professional, Scientific and Technical Services*, and *Educational Services* - the revenue growth effect of 5G technologies will vary across sectors ranging from 0.01% to 5.10%, as shown Figure 23 below.

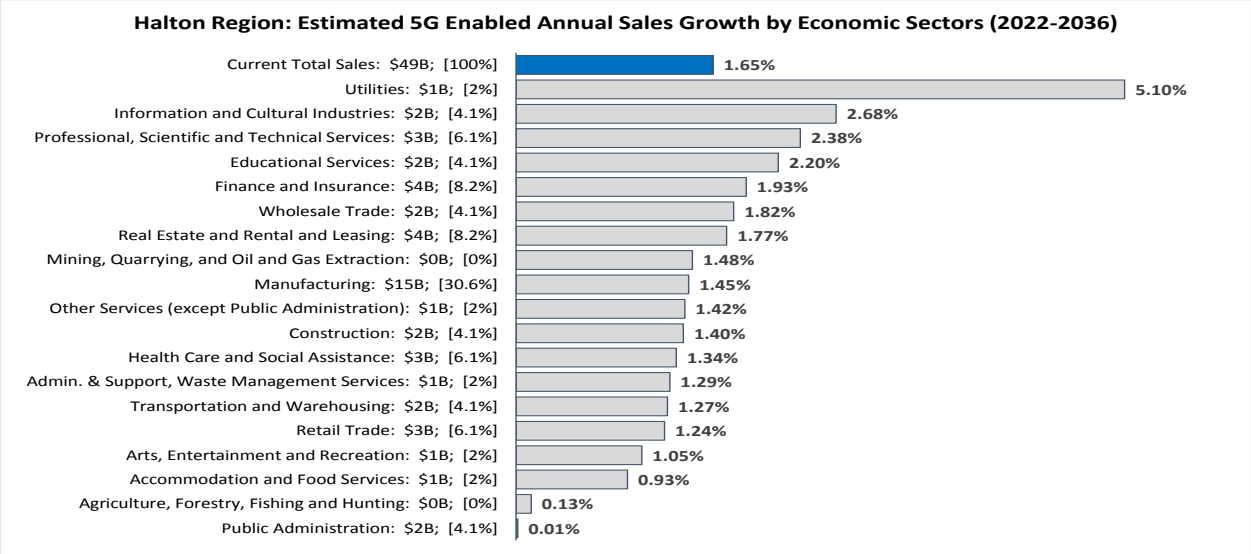


Figure 23: Halton Region: 5G Enabled Annual Sales Growth by Economic Sectors

Source: Nordicity's projections based on Baseline modelling, Statistics Canada Data on emerging technology adoption rates

The basis of our estimates for 5G related revenue growth impacts as shown in Figure 23 above is explained below for the Region's 8 key economic sectors: "***Manufacturing"***, "***Real Estate"***, "***Utilities***", "***e-Health"***, "***Trade"***, "***Transportation"***, "***Information, Culture & Education"***, and "***Finance & Insurance"***.

Manufacturing

Manufacturing is the Region's largest sector representing 30.7% ($15.03 billion) of the total revenues in 2020. While the Canadian manufacturing sector has declined in recent years as production has been 'off-shored' to low labour cost plants, Halton's manufacturing sector remained steady - powered by sectoral expansion in Burlington, and Oakville. In this context, the 5G technology representa an opportunity for Region's manufacturing sector to increase efficiency and competitiveness by facilitating the digitization of factories. 5G technologies will be instrumental in the evolution of next generation of advanced manufacturing systems e.g., *I**ndustry 4.0**.* For example, most of the factory processes, controls, and machines are currently connected through a wired local area network to ensure the reliability of operations. However, wired connectivity alone is not sufficient to address the needs of applications generated by emerging mobility technologies such as guided vehicles, robotics, and drones. Therefore, 5G communications capabilities will be the key enabler for transformation of Industry 4.0 manufacturing processes. That is, *with billions of sensors, machine-controlled robots, and autonomous logistics, all capable of communicating and operating remotely in real-time via 5G networks, manufacturers can achieve massive productivity gains.*[43]

In other words, connected drones, remote robotics, teleoperated driving vehicles, and VR/AR applications enabled by 5G networks will further increase the precision, quality, flexibility of manufacturing facilities. Similarly, various combinations of teleoperated vehicles, remote control robotics and AR/VR applications will significantly reduce costs, increase productivity, and improve on safety in manufacturing industries.

Real Estate

With its 8.3% ($4.08 billion) share in the Region's 2020 total revenue output, the Region's Real Estate appears to be its second major economic sector – also exhibiting the second highest GDP growth rate of 4.38% in 2016-2020. High growth momentum places this sectors in a unique position to gain from digital transformation to be enabled by 5G network deployments. Commercial real estate investors can benefit from leasing space within and on the building envelop, particularly in larger cities. While 4G and previous generations relied on large cell towers, 5G will transmit from many smaller cell towers which telecoms can place on rooftops, inside buildings and on vertical surfaces. The Covid19 crisis imposed several setbacks on the commercial real estate sector with reduced occupancy, new safety regulations, closure of associated business leasing to delay in payments. For this severely impacted sector, the rollout of 5G can present several revenue generating opportunities when the workforce returns to offices.

Besides commercial real estate, residential estate is also set to gain from 5G revolution in form of **connected homes**. Smart Homes with "connected" fixtures and appliances will redefine the way of living. From automatic detection of damage on roofs to reminders for gutters maintenance and grocery refills will improve efficiency around maintenance of property. 5G will support tech and amenities that enhance the occupier experience and strengthen cyber and business security.

Big data analytics will enable smooth collection and management of data around transactions in this sector. Real estate agents, builders and property managers will have unprecedented access to usage analytics. **Virtual Reality** will provide more engaging virtual reality tours that will help buyers looking to buy properties in distant locations, including holiday homes in remote & rural areas. As result one can

expect a surge in demand for properties in less dense areas, making them lucrative & cost-effective options for those who can live and work in remote setups.

Utilities

Utilities represented 3.4% of the Regions' 2020 GDP, increasing from $46.9m (2016) to $501 million (2020) according to our estimates. The sector exhibited a very high GDP growth (24.3%) between 2016 and 2020 primarily driven by its robust performance in Oakville (60% GDP growth) and Halton Hills (27% GDP growth).

Current wireless technologies have enabled the introduction of smart meters and smart grid applications to a certain extent. However, the reliability and latency requirements for certain operations – such as switching electricity sourcing to lowest cost suppliers in real-time e.g. solar to wind according to demand, is currently not offered by current wireless networks.

Utilities are currently faced with rising costs due to increasing system complexities while at the same time, lack the necessary automation tools and real-time preventive controls. 5G can enable **remotely-connected machine intelligence** to real-time preventive control systems.This combined with **connected drones**, and **smart IoT** will enable a significant reduction in costs that can be transferred towards consumer welfare. Furthermore 5G will offer a platform to use civic and energy resources more efficiently and reliably through smart cities and smart grid applications.

5G will facilitate better waste management with applications such as pay-as-you throw digital tracking which monitors and charges for a solid waste disposal using digital technologies and hence reduce the volume of solid waste. The sensors and analytics on water networks can also be used by utilities to manage water resources efficiently thereby reducing water leakages.

e-Health

Healthcare represented 7.3% of the Region's 2020 GDP. The rapid increase in communication technology - adopted by the health sector during the COVID-19 pandemic has laid the foundation for the future of health by enabling several avenues of remote care.

Continuous and **real-time communication** between doctors and patients enhanced by use of 5G technologies, can greatly reduce number of hospital visits and length of hospital stay for patients. This will in turn allow cost savings for patients and better time management by doctors resulting in improved health outcomes.

Advanced technologies like **AI, IoT and big data analytics** showed potential for growth under current Covid crisis. For example, Internet of Things (IoT) are widely used in current pandemic situation by epidemiologists in the process of tracing contacts of infected people, monitoring and managing infected patients who need to quarantine themselves at home, provisioning medical check-ups and remote monitoring of non-infected patients with chronic conditions. This has enabled faster and more accurate collection and sharing of health information both among health systems and between healthcare providers and patients.

While the existing wireless network technologies have enabled a connected health ecosystem comprising of doctors, patients, and health facilities, access to specialized health services such as surgical operations for patients have been a major challenge, due to lack of availability of doctors (surgeons) and fully equipment health facilities in remote and rural areas. 5G can address these challenges by enabling applications such as **remote diagnosis**, **remote imaging**, and **remote surgery**, as they require a very low latency to support reliable audio and video operations.

"Moreover, the haptic feedback enabled by various sensors located on the surgical equipment is also needed in remote surgery such that the surgeons can feel what the robotic arms are touching for precise decision-making…it is haptic feedback that requires the tightest delay requirement with the end-to-end round-trip times (RTTs) lower than 1ms ."[44]

5G networks connected to region's health service centres will enable these applications and vastly increase access to specialized services for residents in rural and remote areas.. 5G-enabled applications promise significant cost savings by reducing the need for transportation and accommodation of patients from rural areas in metropolitan health centres and by enabling better scheduling and utilization of facilities, equipment, professional services in the health sector.

Trade

The Trade sector including both wholesale and retail represented 12.7% of the Region's 2020 GDP. Increased 5G adoption and use by consumers and businesses have enhanced their interactions - thus generating vast new commercial opportunities in sales, marketing, and after-sale customer service. Capturing and analyzing data through analytics, AI and automation have ushered new era of even more immersive shopping experiences. Retailers using online platforms are better able to guide consumers' preferences by pushing personalized ads / offers to their virtual accounts. **Augmented Reality (AR)** allows the customer to visualize the item they wish to shop in a personalized setting. For example, many online furniture stores allow the customer to visualize the furniture item in their room settings, thereby improving the shopping experience and encouraging purchase. Consumers will be able to use high-speed mobile data to have "any time access" to online shopping from the comforts of their home without having to travel to nearby stores for making purchases.

Transportation

Transportation represented 2.7% of the Region's 2020 GDP. The low latency and reliability features of 5G networks will enable major transformations in the transportation sector currently not possible with existing wireless network technologies. For example, while current wireless technologies can provide on-demand information and vehicle-to-vehicle information, **fully autonomous vehicles,** and **fleet platooning** require the ultra-reliability and low latency offered by 5G technology.

The operation of fully autonomous vehicles - in parallel with the roll out of 5G wireless networks, promises to ensure significant improvements in road safety and traffic efficiency as part of a major transformation in the transport infrastructure. Driverless vehicles will require instantaneous and reliable access to data from other vehicles and the surrounding environment to safely automate decisions such as secure spacing between and passing other vehicles.

Fully autonomous vehicles will enhance the productivity of all other sectors that involve vehicle operations, such as warehousing, and particularly mining, construction, manufacturing, health, and so forth. 5G technology will enable advances in e-Transportation that will foster social benefits by making transportation safer as well as making it more accessible for the disabled and elderly populations.

Information, Culture and Education

The Information, Culture and Education sectors combined represented 14% of the Region's 2020 GDP. With 5G, we expect the demand for IT solutions to grow beyond the levels expected before Covid 19 outbreak across sectors including entertainment, gaming, over the top (OTT) platforms and Education Specific solutions such as videoconferencing, intelligent cloud computing, e-learning platforms, and heightened interest in contactless, underscores contribution of 5G technology in assisting businesses and

societies adapt and stay functional in the remote set-up. As a result, we expect wider adoption of digital solutions variously by workers, performers, students, employers, professionals alike.

5G-enabled virtual reality / augmented reality (VR/AR) applications will transform the notions of viewer and audience by enabling 'fully immersive experiences.

The distinctions between 'live' in-theatre and home viewing will be largely removed.
For example, **4K/8K** streaming and **AR/VR** to mobile devices enabled by 5G will enable a fully immersive experience for users at sporting events and live concerts.

Other major 5G applications include AR-enabled city tours, museum guides and remote learning/teaching. Overall, 5G will greatly facilitate the development of new applications and these in turn, will create new demand in this sector driven by factors such as better coverage, consistent and improved customer experience, faster time-to-market, and increased productivity.

Finance and Insurance

The finance and Insurance sector represented 8.8% of the Region's 2020 GDP. As is the case in other sectors, 5G technology will generate incremental demand and productivity in this sector - primarily due to its ultra-reliable capability. Ultra-reliability will ensure secure, instantaneous delivery of financial transactions over wireless networks. Furthermore, instead of onsite visits, banking agents will be able to conduct remote (training, advisory, consultation, transaction handling) sessions with their client. Ultra-reliability and remote session capabilities will increase customer experience and confidence resulting in new demand and significant cost reductions in this sector. **5G-enabled AI advisers** in banks can replace human interaction with customers to help them through their banking needs. Besides banking, insurance companies and investment advisors also use 5G enabled drones to inspect & monitor insured properties to help streamline client management and reduce fraud. 5G applications are instrumental in strengthening security measures such as facial recognition while accessing high value accounts and making transactions more secure and fraud-proof.

Appendix H: 5G Socio-economic Impact Analysis

The $12.4 billion (worth 9.66 billion in present value) incremental revenues (demand) projected to be enabled by 5G roll out in the Region will also attract about $2.56 billion new investment to enable 5G applications across the 19 economic sectors of the Region. About $770 million (30%) of these investments will made by the telecommunications sector, and the remaining $1.79 billion will be invested by the business and industries across all other economic sectors of the Region. These investments represent the estimates for the development and commercialization of 5G-enabled technologies and applications in different economic sectors of the Region such as manufacturing, health care, energy, transportation and so forth.

This means the adoption of 5G wireless technologies in the Region will drive ***new investments*** to deploy 5G applications (use cases) in different business sectors, which will generate **new demand,** and ***productivity improvements.***

To demonstrate economic benefits of 5G technology for the Region our estimates, based on three parallel lines of evidence: l*iterature review, benchmarking, and analysis*, were modelled into the following two main categories.

• ***5G use case benefits*** – incremental sales (demand) and economic gain ratios were developed to estimate the benefits of the development and adoption of 5G technologies in the 19 economic sectors.

• ***5G Investment Impact –*** investments expected by the businesses for adoptions of 5G applications for initial commercialization leading to follow-on investments for adoption on larger scales.

Accordingly for 19 impacted sectors, we developed the cash flow forecasts (incremental revenues and investments) for the 15-year period (2022-2036). As shown in Table 10, the 5G use case cash flows were estimated based on multiplier ratios developed based on the parallel lines of evidence: literature review, historical data on sales, adoption & use of emerging 5G technologies, and an estimation of the factor to determine economic benefits attributable to 5G technologies.

Table 10: 5G Use Case Industry Revenue Impact in Halton Region

Impacted Driver	Incremental Demand	Explanation
Impacted Variable (15 Year - Present Value)	**Revenue: $847 B**	**A**
5G Adjustment factor	1.1%	**B**
Success rate (assumed)	100.00%	**C**
Adjusted Revenue/Productivity Factor	1.140%	**D = B x C**
GDP/Revenue Ratio	n.a.	**E**
Incremental Revenue	**$9.66 B**	**F = A x D**
Total Incremental Revenue	**$9.66 B**	

Based on the historical growth rate of sales for the past 10 years, total sales (demand) for impacted sectors are estimated to be $847 billion over 2022-2036. With the adoption of 5G technologies across the impacted sector, the projected revenues are estimated to increase by additional 9.66 billion (1.14%).

To enable these incremental revenues the businesses in the Region will deploy 5G applications (use cases), which according to our estimate will result in new investment of $2.56 billion as shown in Table 11 below.

Table 11: 5G Investment Impact in Halton Region

Impacted Driver	5G Tech Investment	Explanation
Impacted Variable (15 Year - Present Value)	**Revenue: $847B**	**A**
5G Adjustment factor	1.1%	**B**
Average Capital Intensity	7.95%	**C**
Initial Incremental Investments	**$0.77 B**	**D=A x B x C**
Follow on investment factor (assumed)	2.33	**E**
Follow-on Investments (3 Yr. lag)	**$1.8 B**	**F = D X E**
Total Investment	**$2.56 B**	**G= D + F**

HALTON REGION ECONOMIC IMPACT ANALYSIS

The overall 5G-enabled economy is expected to generate total GDP of **$12.25 billion** and **91,644** jobs in the Region in 2022-2036.

- The total GDP impact of $12.25 billion includes the direct impact of $6.22 billion, the indirect impact of $2.97 billion, and the induced impact of $3.05 billion.
- The total employment impact of 91,644 includes the direct impact of 49,103, the indirect impact of 20,752, and the induced impact of 21,788.

	Halton | Total 5G Economic Impact			
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	49,103	20,752	21,788	91,644
Gross Domestic Product ($ million)	$6,223	$2,971	$3,051	$12,246

The total 5G GDP and employment impact as above will include 5G Investments and 5G Use Case impact. The 5G investment will generate overall GDP of **$2.28 billion** and 18,977 jobs over 2022-2036.

- The GDP impact of $2.28 billion includes the direct impact of $1.02 billion, the indirect impact of $0.62 billion, and the induced impact of $0.64 billion.
- The total employment impact of 18,977 includes the direct impact of 10,007, the indirect impact of 4399, and the induced impact of 4571.

	Halton		5G Investment Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	10,007	4,399	4,571	18,977
Gross Domestic Product ($ million)	$1,023	$615	$640	$2,279

The adoption and use of 5G technologies across the Region are expected to generate overall GDP of **$9.97billion** and **72,667** jobs over 2022-2036.

- The GDP impact of $9.97 billion includes the direct impact of $5.20 billion, the indirect impact of $2.36 billion, and the induced impact of $2.41 billion.
- The total employment impact of 72,667 includes the direct impact of 39,097, the indirect impact of 16,353, and the induced impact of 17,217.

	Halton		5G Use Case Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	39,097	16,353	17,217	72,667
Gross Domestic Product ($ million)	$5,200	$2,356	$2,411	$9,967

BURLINGTON ECONOMIC IMPACT ANALYSIS

Burlington is expected to constitute 36% of Halton's 5G-enabled economy with a GDP contribution of **$4.43 billion** and **33,466 additional jobs** in 2022-2036.

	Burlington |		Total 5G Economic Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	17,512	7,779	8,175	33,466
Gross Domestic Product ($ million)	$2,164	$1,118	$1,145	$4,427

The total 5G GDP and employment impact in Burlington, as above will include 5G Investments and 5G Use Case impact as below.

	Burlington		5G Investment Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	3,185	1,376	1,422	5,983
Gross Domestic Product ($ million)	$303	$192	$199	$695

	Burlington		5G Use Case Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	14,327	6,403	6,753	27,483
Gross Domestic Product ($ million)	$1,861	$925	$946	$3,732

OAKVILLE ECONOMIC IMPACT ANALYSIS

Oakville's 5G-enabled economy is expected to generate a GDP contribution of **$5.13 billion**, and **37,458 additional jobs** over 2022-2036, reflecting 42% of Halton's 5G driven growth.

	Oakville		Total 5G Economic Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	20,492	8,292	8,674	37,458
Gross Domestic Product ($ million)	$2,734	$1,179	$1,215	$5,128

The total 5G GDP and employment impact in Oakville, as above will include 5G Investments and 5G Use Case impact as below.

	Oakville		5G Investment Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	4,561	2,074	2,163	8,797

Gross Domestic Product ($ million)	$502	$290	$303	$1,094

	Oakville		5G Use Case Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	15,931	6,218	6,512	28,661
Gross Domestic Product ($ million)	$2,233	$889	$912	$4,034

MILTON ECONOMIC IMPACT ANALYSIS

Milton is expected to constitute 13% of Halton's 5G-enabled economy with a GDP contribution of **$1.62 billion** and **12,397 additional jobs** over 2022-2036.

	Milton		Total 5G Economic Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	6,903	2,683	2,810	12,397
Gross Domestic Product ($ million)	$839	$382	$394	$1,616

The total 5G GDP and employment impact in Milton, as above will include 5G Investments and 5G Use Case impact as below.

	Milton		5G Investment Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	1,350	567	588	2,505
Gross Domestic Product ($ million)	$133	$79	$82	$295

	Milton		5G Use Case Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	5,553	2,116	2,222	9,892
Gross Domestic Product ($ million)	$706	$303	$311	$1,321

HALTON HILLS ECONOMIC IMPACT ANALYSIS

With a 9% share in Halton's 5G-enabled economy, Halton Hills is expected to generate a GDP contribution of **$1.11 billion** and **8,487 additional jobs** over 2022-2036.

	Halton Hills		Total 5G Economic Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	4,376	1,994	2,116	8,487
Gross Domestic Product ($ million)	$524	$290	$296	$1,110

The total 5G GDP and employment impact in Hilton Hills, as above will include 5G Investments and 5G Use Case impact as below.

	Halton Hills		5G Investment Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	928	397	414	1,740
Gross Domestic Product ($ million)	$90	$56	$58	$204

	Halton Hills		5G Use Case Impact	
	Direct impact	*Indirect impact*	*Induced impact*	*Total impact*
Employment (FTEs)	3,448	1,597	1,702	6,747
Gross Domestic Product ($ million)	$434	$234	$238	$906

TOP FIVE SECTOR DRIVING 5G BENEFITS IN THE REGION

As shown in Figure 24 and Figure 25, 5G technology is expected to enhance the growth prospects of GDP and jobs in the ***manufacturing*** sector across all four municipalities. Improved efficiency and effectiveness in production facilities and its supply chain will dominate the benefits unleashed by adoption of 5G technologies by Halton's advanced manufacturing sectors comprising some 1,150 manufacturers – employing 34,750 professionals and 125 engineering firms, employing 3,825 professionals.[45] Besides manufacturing, 5G is set to offer improvements and opportunities in a wide array of sectors, including ***Information and Cultural Industies***, ***Real Estate***, ***Utilities***, ***Professional Services***, ***Trade, Finance & Insurance***, and ***Education***, through 5G enabling technologies, such as cloud computing, IoTs and AI.

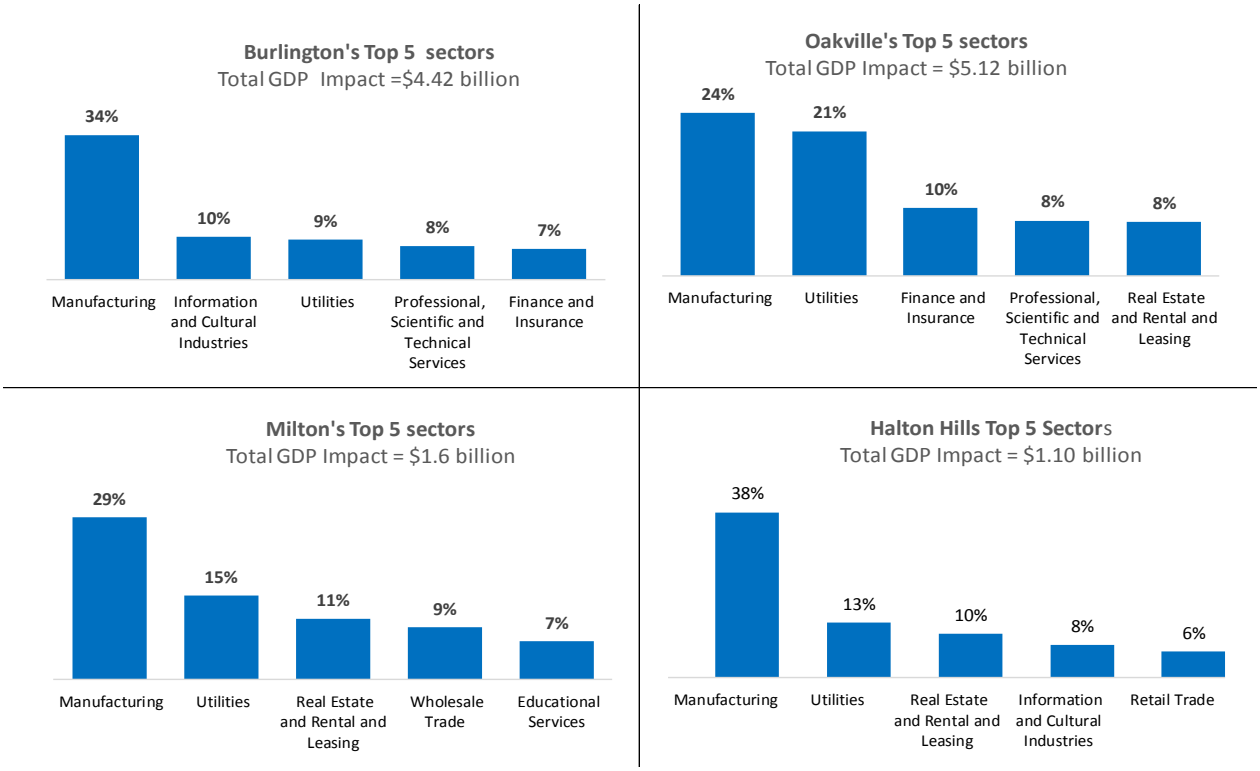


Figure 24: Top 5 impacted sectors by share in total GDP impact in each municipality

Note: Sectors are ranked according to share in respective 5G total GDP Impact

Figure 25: Top 5 impacted sectors by share in total employment impact in each municipality

Note: Sectors are ranked according to share in respective 5G total employment Impact

Appendix I: Methodology

The entire modelling exercise followed a two-stage process. In the first stage, our project team analyzed the status of the digital economy sector in Halton Region and its four municipalities.

In the second stage, a forecast of macroeconomic impacts of 5G technology was developed with 15-year projections (2022-2036). For both the stages, distinct economic models were created to estimate the contribution of digital technologies to the Halton Economy and its municipalities.

At the outset, Halton and municipal economies were divided into 20 sectors according to North American Standard Industrial Classification of all Economic Activities (NAICS). Macro-economic data from StatsCan (Canada's National Statistical Agency) and employment data from Halton Employment survey was used to estimate each economic sector's GDP, Output, and other financial metric including sales, capital intensity and compensation of employees.

Economic Baseline Model:

The Halton's digital sector was classified into 7 verticals based on type of digital economic activities using Canadian Digital- Supply and Use Tables published by StatsCan and insights developed using Halton's Employment Survey.

While the Halton Employment Survey captures businesses with physical presence (office building, stores, etc.), required adjustments & approximations were made to account for businesses with online presence only (for example non-store retailers) that constitute an integral part of digital economy. Adjustments made to the data were guided by the underlying assumption that the Digital intensity of each sector at sub-provincial level is same as what exists at national level. While this assumption has limitations, there is currently lack of available data on digital metrics at sub-provincial levels.

Canadian Digital Supply and Use tables were then used to extract relevant information on contribution of Digital industries to sectoral GDP at the national level.

The resulting information was later used to:

1) Impute values for businesses which have online presence and were hence not captured in employment survey
2) Estimate the proportion of digital goods and services produced by non -digital industries.

Finally, the data for each of the seven digital economy verticals were mapped to Input-Output tables (matrix) in our model to determine their respective economic impact results: GDP, Employment, and Productivity.

The Input-Output Modelling approach encompasses quantitative economic impact assessment by mapping the interdependencies between different sectors of a national economy. The symmetric Input-Output Tables, also known as Input-Output Analytical Tables are derived from the "Supply" and "Use" Tables that form a central part of the system of National Accounts. The main use of these tables is to act as an integration framework for balancing the national accounts and determining an estimate of GDP.

Input-Output tables (I-O Tables) derived from "Supply" and "Use" tables are recognized as the basis for a wide range of macroeconomic models and economic impact analyses.

StatsCan's 2017 input-output table for the province of Ontario was used to develop output and GDP multipliers. Two types of multipliers are used to determine the economic impact, "***Type I Multipliers***" and "***Type II Multipliers***". Type I Multipliers sum together direct and indirect effects while Type II Multipliers also include induced effects

Technically, GDP is comprised of Operating Surplus and labour Income. Our team isolated the incremental labour income from this incremental GDP using the Statistics Canada's Input-Output Tables (Ontario province).

The number of jobs was then calculated using estimated incremental labour income and the information on average industry-wise compensation published by Statistics Canada.

Both GDP and employment impact was disaggregated into the direct, indirect, and induced effects as described below:

- **Direct impact:** Refers to GDP and employment generated due to direct expenditure made by digital industries or in simple terms the value added by the digital industries
- **Indirect impacts:** Refers to GDP and employment generated by the sub-industries that supply inputs to economic agents described above. These digital industries they purchase inputs from other industries called the supplier industries, so when the digital production increases the production of these supplier industries also increases. Indirect impacts capture that part of supplier industries' GDP and employment that is generated while providing inputs to digital industry.
- **Induced impact:** Refers to GDP and employment generated through the re-spending of income earned by the participants in the direct and indirect expenditure ecosystem described above. That is, induced impacts arise from re-spending that occurs in the economy at the household level, e.g., employees of participating firms using their income to purchase goods and services in the general economy.
- **Total economic impact:** The total economic impact is equal to the sum of the direct, indirect, and induced economic impacts.

Economic Impact Forecast Model

From an economic perspective, there are two main drivers of economic impact of 5G adoption and use:

1) Investments made in 5G technology contributes *directly* to GDP via the network build-out. The deployment of 5G infrastructure requires heavy investments in equipment and labor, such as the construction of new wireless towers and data centers, upgrades of existing sites to add 5G capabilities, and development of new network architecture and supporting software. These investments generate demand for additional inputs and labor resulting in a substantial impetus to GDP and employment.
2) 5G use case Impact: As 5G infrastructure expands, it boosts the uptake 5G applications by enabling improvements to existing applications and development of new use cases across industries. This would add new revenue streams in the sector and generate employment within the economy.

   5G adoption and use comes along with advances in speed, latency, and capacity – all leading to productivity improvement across sectors. Besides technical efficiencies – 5G would also enable more efficient and high valued services across businesses.

At its core, the model provides an assessment of how adoption of 5G technologies generates ripples of economic activity through the Halton Region resulting in incremental sales and complimentary capital expenditure.

To estimate the socio-economic contribution of 5G technologies in the Halton Region, a comprehensive modeling approach was applied as illustrated in Figure 26 below[46]:

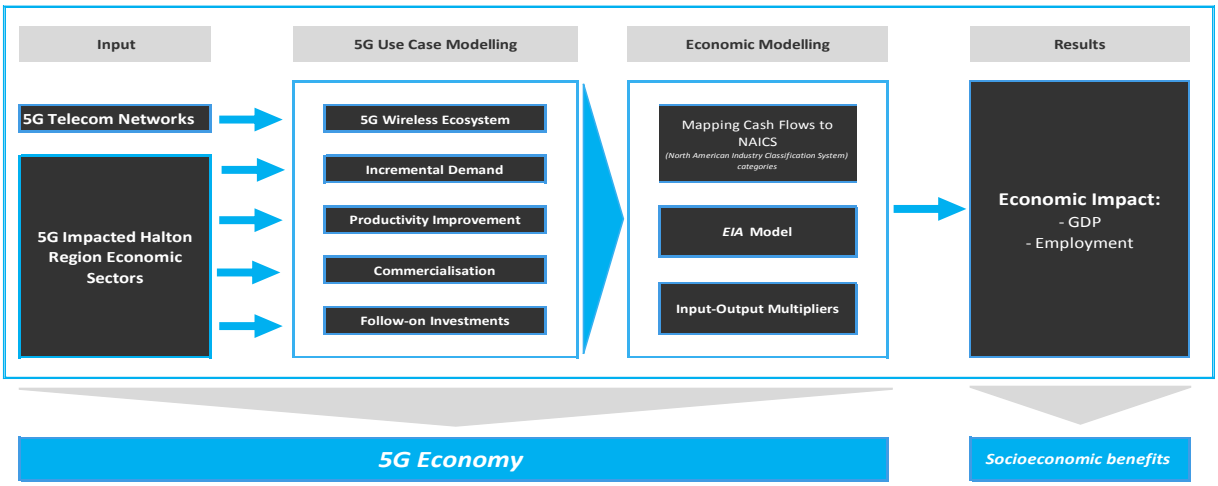


Figure 26: 5G Economic Impact Analysis Modelling Framework

As shown above, based on the modelling of applicable 5G use case for Halton Region's and four municipalities' economic sectors, we develop a 10-year forecast financial model, which is then converted into GDP and employment impacts. That is, we map the outputs of the financial model to the NAICS (North American Industry Classification System) categories, after conversion into present values using a suggested 3% hurdle rate[47]. Finally, EIA Model is used to estimate economic impact results (GDP, Employment), based on Stats Canada relevant Input-Output (I-O) multipliers. The economic impact assessment (GDP and employment) is including the direct, indirect, and induced effects, as described below:

Economic Impact Type	5G Wireless Ecosystem	Commercialization of Research and Development
Direct Impact	Jobs and economic activities created and retained in the Region because of the deployment and operation of 5G Wireless networks in the Region.	Jobs and economic activities generated as result of demand generation, productivity improvement, and new investments, attributable to the development, commercialization of 5G-enabled technologies in the Region.
Indirect Impact	Jobs and economic activities generated by purchases of equipment, supplies and services from other industries	
Induced Impact	Employment and economic activities generated by direct and indirect workers' re-spending of labor income in the Region	

Glossary

1xRTT:	Single-Carrier Radio Transmission Technology
3GPP:	"3rd Generation Partnership Project" between groups of telecommunications associations
AR:	Augmented Reality
AV:	Autonomous Vehicle
CAGR:	Compound Annual Growth Rate
CMDA:	Code Division Multiple Access Technology
CO:	Central Office (Telephone Exchange)
CSA:	Climate Smart Agriculture
eMBB:	Enhanced Mobile Broadband
EVDO:	Evolution-Data Optimized
FDMA:	Frequency Division Multiple Access
FTE:	Full-time equivalent (of an employee)
FWA:	Fixed Wireless Access
Gbps:	Gigabit Per Second
GDP:	Gross Domestic Product
GHz:	Gigahertz
GSM:	Global System for Mobile Communication
HD:	High Definition
HSPA:	High Speed Packet Access
Hurdle Rate	Refers to the minimum rate of return acceptable to stakeholders on a capital investment project.
ICT:	Information and Communication Technology
IMT:	International Mobile Telecommunication system
I-O:	Input-Output
IoT:	Internet of Things
ISED:	Ministry of Industry Science and Economic Development (ISED) of Canada
Kbps:	Kilobit Per Second
LTE:	Long-Term Evolution (LTE) - 4G Mobile Communications Standard
MHz:	Megahertz
mMTC:	Massive Machine Type Communications
ms:	Millisecond
EIA Model:	Economic Impact Assessment Model
NAICS:	North American Industry Classification System
OFMDA:	Orthogonal Frequency-Division Multiple Access
PSTN:	Public Switched Telephone Network
RAN:	Radio Access Network
RTT:	Round-Trip Time or Round-Trip Delay Time (RTD) i.e., length time to send and receive a signal
UMTS:	The Universal Mobile Telecommunications System
uRLLC:	Ultra-reliable and Low-latency Communications
VR:	Virtual Reality

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[1] Nordicity (www.nordicity.com) was assisted by its partner firm NE&S: Networks, Economics & Strategy Inc. (www.nesglobe.com) in the completion of this study

[2] See United Nations (UN) 2030 Agenda for Sustainable Development. According to the UN 2030 Agenda widespread and equitable access to digital technology are instrumental in achieving a country's sustainable economic development goals (SDG). For example, enhanced digital capabilities help build resilient infrastructure, promote sustainable industrialization, and foster innovation (SDG # 9). It is also instrumental in creating economic and social value across industrial sectors of the economy. For instance, smart and automated manufacturing along with improved digital performance management results in enhanced operational efficiency enabling responsible consumption and production (SDG # 12). Similarly, adoption of advanced digital technologies in health sector will ensure good health and promote well-being for all (SDG# 3), eradicate poverty (SDG # 1); ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (SDG # 4), gender equality (SDG # 5), generate productive employment and economic growth (SDG# 8), reduce inequality (SDG # 10), and build strong institutions (SDG # 16)

[3] Existing broadband network technologies such as wireline: Copper-Based (DSL), Coaxial Cable Based wireline, and wireless: 4G/LTE has limitations in terms of meeting future demand for higher speed (over 1Gig Mbps) for internet connectivity and supporting exponential growth in internet traffic (volume). Modern broadband network technologies such as FTTH (Fibre to the home) and 5G Wireless do not have such speed and capacity constraints.

[4] See Ciena White Paper, **"Five Key Wireline Network Improvements Needed for 5G"** https://media.ciena.com/documents/Five-Key-Wireline-Network-Improvements-Needed-for-5G_WP.pdf

[5] The 5G Economy Qualicom study See: https://www.qualcomm.com/invention/5g/economy

[6] "*The US and Canada are notable examples of markets where migration to next-generation devices and networks as been fast. Both were among the first few countries in the world to reach 50% smartphone adoption in 2012, and 50% LTE adoption three years later"* (GSMA, 2017, "*The Mobile Economy North America* 2017")

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[16] US Federal Communications Commission: Source: https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/faq/rf-safety

[17] https://www.knowyourmobile.com/phones/the-history-of-mobile-phones-from-1973-to-2008-the-handsets-that-made-it-all-happen-d58/

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[19] Also referred to as RF-EMF or radiofrequency - electromagnetic field spectrum. RF-EMFs range in frequency from 3 kilohertz (kHz) to 300 gigahertz (GHz).

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[32] *"We recognize that a well-developed broadband infrastructure is essential for Canadians to participate in the digital economy. (https://crtc.gc.ca/eng/internet/performance.htm)*

[33] For example, 2021 Business Plan of Northumberland County, ON states "….broadband connectivity in the County is essential to sustainable growth. Work on the development of a Broadband Strategy aims to address these challenges" (https://www.northumberland.ca/en/county-government/resources/Documents/2021-Budget-Docs/BP-and-IP/IT-2021-Draft-BP-IP.pdf)

[34] Based on our past experience we believe it is reasonable to assume that our assessment represents broadband coverage in the Region with +/(-) 20% accuracy level.

[35] Gigabit service is any service with a downstream data rate at or above 940 Mbps (CRTC CMR 2019, p.276)

[36] A unified broadband network means an integrated fibre based wireline network delivering broadband connectivity services across the Region, using uniform standards in terms of internet speed capability and quality of service.

[37] https://crtc.gc.ca/eng/archive/2020/2020-366.htm

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[39] In order to model the socio-economic benefits of 5G technologies we assumed the next generation future proof broadband network infrastructure (both wireline and wireless) will be deployed in the Region over the next 3-5 years. If these deployments are delayed, realisation of 5G benefits in the Region will also be delayed accordingly,

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