Deep Dives and Case Studies for TELUS Priority Verticals: Health

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5.1 Deep Dives and Case Studies for TELUS Priority Verticals

5.1.1 Health

Key Takeaways

- Key challenges faced by the healthcare industry include escalating expenditures; fewer medical resources; an aging global population; health impacts stemming from climate change; barriers to healthcare for rural and remote populations; and growing socio-economic gaps that drive discrepancies in the quality of people's health.
- 5G will be an enabler of various innovative applications that could mitigate or even eliminate the challenges listed above and facilitate a healthcare ecosystem that aligns with 4P medicine – predictive, preventative, personalized and participatory. These digital 5G solutions include real-time patient monitoring, remote diagnostics and surgery, and predictive analytics; AR/VR-enabled medical training and patient care; drone-enabled medical supply delivery; interactive smart pharmaceutical devices; distributed AI capable of personalized patient treatment; and medical telecare.
- These 5G solutions could facilitate a reduction in the likelihood of medication and medical errors, enhance remote diagnosis, imaging, surgery, patient monitoring and medical training; allow fast and reliable medical data sharing; reduce healthcare expenditures on facilities and equipment; and remove the need for human involvement in some medical procedures.

Industry overview: Access to an effective and efficient healthcare ecosystem is crucial to how individuals perceive their quality of life. The healthcare sector accounts for approximately 10% of total global GDP.[1] In Canada, total health expenditure as a proportion of GDP has risen to 12.7% in 2021[2] from 7.0% in 1975.[3] Today, insufficient public funding is challenging Canadian healthcare providers and recipients. Three studies indicate that Canada's healthcare does not compare favorably to peer countries, as highlighted in the key findings summarized below.[4]

Challenges faced by the healthcare industry:

[1] Link to report: https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS
[2] Link to report: https://www.cihi.ca/en/national-health-expenditure-trends-2021-snapshot#:~:text=It%20is%20anticipated%20that%20health,high%20of%2013.7%25%20in%202020
[3] Link to report: https://www.cihi.ca/sites/default/files/document/nhex-trends-narrative-report-2019-en-web.pdf
[4] Link to reports: 1) https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf; 2) https://www.commonwealthfund.org/publications/fund-reports/2021/aug/mirror-mirror-2021-reflecting-poorly; 3) https://www.fraserinstitute.org/sites/default/files/waiting-your-turn-2020-execsum-national.pdf. The challenges identified for the healthcare sector are more specific to Canada as opposed to other industry sectors in this report where the challenges are more generalized. Key factors that may be responsible for this underperformance are: 1) 5th highest rural population among G10 nations; 2) lowest population density among G10 nations; 3) highest population growth amongst G10 nations; and 4) 2nd highest migrant population amongst G10 nations. https://www.theglobaleconomy.com/

1. **Escalating healthcare expenditures:** According to the WHO, there is a worldwide health worker shortage that is jeopardizing social services and sustainable health systems. The world will need 18 million additional health workers by 2030, primarily in low- and middle-income countries, including 9 million nurses and midwives.[5] A Fraser Institute study suggests that "there is an imbalance between the value Canadians receive and the relatively high amount of money they spend on their healthcare system. Although Canada ranks among the most expensive universal-access healthcare systems in the OECD, its performance for availability and access to resources is generally below that of the average OECD country, while its performance for use of resources and quality and clinical performance is mixed."[6] Out of 28 countries, after adjusting for age, Canada ranks second highest for healthcare expenditure as a percentage of GDP and 10th highest for healthcare expenditure per capita.[7] These indicators suggest that Canada spends more on healthcare than most high-income OECD countries with universal healthcare systems.[8]

2. **Fewer human and capital medical resources per capita:** Canada has fewer human and capital medical resources per capita when compared to other high-income OECD countries with universal health care. After adjusting for age, Canada ranks 26th out of 28 countries in terms of the number of physicians, 13th for nurses, 26th for curative (acute) care beds (out of 27), and 25th for psychiatric care beds per 1,000 people across all the identified metrics.[9]

3. **Fewer technology and diagnostic imaging resources:** Canada has, on an age-adjusted basis, fewer medical technologies than the average high-income OECD country with universal healthcare for which comparable inventory data is available. After adjusting for age, Canada ranks 21st out of 26 countries in terms of the number of MRI units per million people, 21st out of 27 countries for CT scanners, 17th out of 22 countries for PET scanners, 2nd out of 21 countries for Gamma cameras and 12th out of 19 countries for Mammography.[10]

4. **Mediocre performance on use of resources:** Canada's performance is mixed on our efficient use of resources. After adjusting for age, Canada ranks 9th out of 26 countries for the number of doctor consultations per capita, 28th out of 28 countries for hospital discharge rates per 100,000 population, 14th out of 25 countries for the number of MRI

[5] Link to report: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade
[6] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf
[7] The countries included for comparison in this study were chosen based on the following three criteria: 1. must be a member of the OECD; 2. must have universal (or near-universal) coverage for core-medical services; 3. must be classified as a "high-income" country by the World Bank. Of 35 OECD members in 2017 considered for inclusion, the OECD (2017) concluded that six countries - Chile, Greece, Mexico, Poland, the Slovak Republic, and the United States did not have universal (or near-universal) coverage for core medical services. Of the 29 countries remaining for consideration, Turkey does not meet the criteria of being classified in the high-income group (in 2017) according to the World Bank (2019). The remaining 28 countries that meet the three criteria above can be seen in table 2 (p. 9).28 countries with universal health-care systems are – Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom.
[8] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf
[9] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf
[10] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf

examinations per 1,000 people, and 12th out of 25 countries for CT scans per 1,000 people.[11]

5. **Low performance on timeliness and access to resources:** Canada is tied for last place out of 10 countries for the percentage of patients able to make a same-day appointment when sick and ranks 4th out of 10 countries for the percentage of patients who report that it is very or somewhat easy to find care after hours. Canada placed last among 17 countries for the percentage of patients who reported waiting more than four weeks for an appointment with a specialist. Canada also ranked worst (10th out of 10 countries) for the percentage of patients who reported waiting two months or more for a specialist appointment and worst (10th out of 10 countries) for the percentage of patients who reported waiting four months or more for elective surgery. Canada placed at or near the bottom among other countries with universal-access healthcare systems on four out of five indicators of timeliness of care. It performed better than average for patients who reported it was very or somewhat easy to find care after hours, ranking 4th out of 10 countries. However, Canada performed worse than the 10-country average for the percentage of patients who found that cost was a barrier to access, ranking 7th out of 10.[12] Canada also has the lowest hospital discharge rate per 100,000 people of those countries in the study.[13]

6. **Aging global population puts yet another pressure on the healthcare system:** Populations in the West and the East are aging rapidly. The number of people aged 65+ years is projected to increase from 8.5% of total global population in 2015 to 12% of total global population by 2030 and to 16.7% by 2050.[14] More than 1 in 5 (21.8%) Canadians of working age are aged 55 to 64 and are nearing retirement. This is an all-time high in the history of Canadian censuses.[15] As a growing number of workers leave the workforce in the years ahead, a smaller cohort of the working-age population will need to work harder to maintain Canada's standard of living, to support the production of goods and services and bear the financial burden of the increasing social service needs, including healthcare, for the aged.

7. **Climate change will continue to aggravate the health crisis we are currently facing:** Air pollution accounts for approximately 7 million deaths every year and climate change causes more extreme weather events, exacerbates malnutrition, and fuels the spread of infectious diseases such as malaria.[16] The same emissions that cause global warming are responsible for more than one-quarter of deaths from heart attacks, strokes, lung cancer and chronic respiratory diseases.[17]

[11] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf
[12] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf
[13] Link to report: https://www.fraserinstitute.org/sites/default/files/comparing-health-care-countries-2019.pdf
[14] Link to report: https://www.researchgate.net/profile/Paul-Kowal/publication/299528572_An_Aging_World_2015/links/56fd4be108ae17c8efaa1132/An-Aging-World-2015.pdf
[15] Link to report: https://www150.statcan.gc.ca/n1/daily-quotidien/220427/dq220427a-eng.htm?CMP=mstatcan
[16] Link to report: https://www.who.int/data/gho/data/themes/air-pollution
[17] Link to report: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade

8. **Medication errors and adverse drug events continue to drive unnecessary costs, decreased patient satisfaction and a growing lack of trust in the healthcare system:** Unsafe medication is responsible for considerable and potentially avoidable morbidity and mortality. The World Health Organization (WHO) has initiated the third Global Patient Safety Challenge on Medication Safety to improve medication safety by strengthening the systems for reducing medication errors and avoidable medication-related harm. The overarching goal of the Challenge is to reduce the level of severe, avoidable harm related to medications by 50% over five years, globally.[18] Medication safety issues can impact health outcomes, length of stay in a healthcare facility, readmission rates and overall costs to Canada's healthcare system. Preventable medication hospitalizations cost over CA$140 million in direct and indirect healthcare expenditures, with lost productivity, including time off work, adding CA$12 million in costs.[19] Globally, the cost associated with medication errors has been estimated at over $55 billion.[20] The WHO's Challenge aims to make improvements at each stage of the medication process, including prescribing, dispensing, administering, monitoring and use.

9. **Rural populations continue to encounter barriers to healthcare that limit their ability to obtain the care they need:** Access to quality healthcare in remote/rural areas is another critical challenge for the world. Significant differences exist between urban and rural populations in terms of health status, health behaviors, health service use, costs and outcomes. In general, rural residents have direct access to a much smaller number and scope of health services and providers than urban residents. Decision-makers and planners frequently face challenges regarding the availability, capacity, sustainability and performance of rural health systems.[21] In Canada, rural populations in Canada are generally older, less affluent and sicker. Almost one-fifth of Canadians (18%) live in rural communities, but they are served by only 8% of the physicians practicing in Canada.[22,23] These communities face ongoing challenges in recruiting and retaining family physicians and other healthcare professionals. People in rural areas face more difficulty accessing the healthcare system than their urban counterparts, and when they do access healthcare, they have poorer outcomes.[24]

10. **Persistent and growing socio-economic gaps are driving major discrepancies in the quality of people's health:** The global rise in long-term, noncommunicable conditions, such as obesity, heart disease, cancer, chronic respiratory disease, diabetes, depression,

[18] Link to report: https://www.patientsafetyinstitute.ca/en/NewsAlerts/News/pages/medication-without-harm-2018-09-14.aspx
[19] Link to report: https://www.patientsafetyinstitute.ca/en/NewsAlerts/News/pages/medication-without-harm-2018-09-14.aspx
[20] Link to report: https://www.patientsafetyinstitute.ca/en/NewsAlerts/News/pages/medication-without-harm-2018-09-14.aspx
[21] Link to report: https://www.cihi.ca/en/rural-health-care-in-canada
[22] Link to report: Canadian Institute for Health Information. Supply, distribution, and migration of physicians in Canada 2015-data tables. Ottawa, ON: Canadian Institute for Health Information; 2016. Data accessed at: https://secure.cihi.ca/estore/productSeries.htm?pc=PCC34.
[23] Link to report: Bosco C, Oandasan I. Review of family medicine within rural and remote Canada: education, practice, and policy. Mississauga, ON: College of Family Physicians of Canada; 2016. Link to report: https://www.cfpc.ca/CFPC/media/Resources/Rural-Practice/ARFM_BackgroundPaper_Eng_WEB_FINAL.pdf.
[24] Link to report: Subedi R, Greenberg TL, Roshanafshar S. Does geography matter in mortality? An analysis of potentially avoidable mortality by remoteness index in Canada. Ottawa, ON: Statistics Canada; 2019. Link to report: https://www150.statcan.gc.ca/n1/pub/82-003-x/2019005/article/00001-eng.htm.

dementia and musculoskeletal disorders, places a disproportionately large burden on low- and middle-income countries and poorer households.[25] Every year, the world spends far more money responding to disease outbreaks, natural disasters and other health emergencies than it does preparing for and preventing them. It is not a matter of if another COVID-19 type pandemic will strike, but rather when. Meanwhile, vector-borne diseases like dengue, malaria, Zika, chikungunya and yellow fever are spreading as mosquito populations move into new areas, due to climate change.[26]

11. **Patients demand similar experience levels with healthcare as they do with other services:** Quality of care has become very important to patients, and they have more options today as to how and with whom they get their care. They are demanding transparency of data and processes, and privacy and security assurances for personal records. Patient advocacy groups and the patients themselves, armed by social media, are pushing for deeper investigations of matters such as medication errors, hospital-acquired infections, and wrong-site surgery.

12. **Other healthcare challenges:** There are numerous other healthcare challenges, including a lack of transportation to healthcare centres, cumbersome hospital registration systems, and a hierarchical medical system. Meanwhile, there are opportunities to shift to more personalized and customized treatment that reflects a holistic view of the patient while advocating for standardized guidelines and treatment procedures. Another common phenomenon in developing countries and regions is overcrowding in hospitals, resulting in overloaded medical staff. An imbalance of health resources, including medical equipment and well-trained practitioners, causes large numbers of patients to travel from rural areas to urban areas seeking high-quality health service. Medical staff, in the provision of healthcare services, rely heavily on their own experience rather than data.

Enhancements to services enabled 5G such as remote robotic surgery, remote patient monitoring, telemedicine, clinical collaboration and communication, medical sensors, connected ambulances, computer-aided diagnostics, and medical imaging will allow both patients and the healthcare ecosystem to mitigate or possibly eliminate these challenges. Enhancement of current technologies and applications and the introduction of innovative technologies and applications like 5G are revolutionizing patients' ability to prevent, diagnose and treat many diseases. This new 5G enabled ecosystem will align with the recent phenomenon of 4P medicine – predictive, preventative, personalized and participatory. 5G will also allow more rural/remote post-acute care and home-based models, with savings greater than 30% and better patient outcomes.[27]

Potential Digital Solutions Supported by 5G	Types of 5G Capabilities Leveraged

[25] Link to report: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade
[26] Link to report: https://www.who.int/news-room/photo-story/photo-story-detail/urgent-health-challenges-for-the-next-decade
[27] Link to report: https://www.accenture.com/ca-en/insights/high-tech/5g-economic-impact

1. **Continuous monitoring**[28] provides constant monitoring and processing of numerous sensory devices. This capability will facilitate continuous monitoring of patients through wearable devices, substantially increasing the effectiveness of preventative care. This will potentially lower the burden of chronic disease management experienced by healthcare systems globally. 2. **Predictive analytics**[29] capability harnesses the data generated by continuous monitoring to even greater effect. While continuous monitoring will power the development of new data streams, the use of distributed computing – the processing of patient data nearer to the patient – will power predictive analytics and intelligent care based on the new data streams. 3. **Remote diagnosis and imaging**[30] enables the application of virtual reality, which will have important benefits in the delivery of medical care (e.g., in the diagnosis and treatment of critical medical episodes such as strokes). 4. **Remote surgery,**[31] also known as telesurgery, enables a doctor to perform surgery on a patient even though they are not physically in the same location. It is a form of telepresence; a robot surgical system generally consists of one or more arms (controlled by the surgeon), a master controller (console) and a sensory system giving feedback to the user. 5. **Image transfer**[32] enables medical image sharing to facilitate transfers between other care facilities that may or may not be on the same network and to referring physicians in the community, as well as directly to patients. 6. **AR/VR-enabled healthcare**[33] enables applications including medical training, surgical planning, pain management, patient care management and mental health treatment. 7. **Drone-enabled medical service delivery**[34] enables the fast delivery of vaccines, medications and supplies right to the source. This capability could limit outbreaks of life-threatening communicable diseases. 8. **Equipment monitoring** enables hospital management to continuously monitor technology	1. **Ultra-low and predictable latencies with quality-of-service guarantees (URLLC)** - even with a heavy load and many users. 2. **Extremely high bandwidth for data transmission (eMBB)**, enabling transfer and download of massive data files, high-resolution images, videos and supporting AR/VR. 3. **Massive IoT (mIoT)** - 5G will be able to facilitate a large network of IoT devices and sensors. 4. **Fixed wireless access (FWA)** - ultra-low-cost networks in rural areas. 5. **More deployment flexibility** for sparse and dense options. **6. Mobility capabilities to ensure a smooth handover** between base stations. 7. **Reliability of device interoperability** and low device cost at scale. 8. **Location awareness** for navigating, real-time locating, and positioning.

[28] Link to report: https://haas.berkeley.edu/wp-content/uploads/5g-mobile-impact-on-the-health-care-sector.pdf
[29] Link to report: https://haas.berkeley.edu/wp-content/uploads/5g-mobile-impact-on-the-health-care-sector.pdf
[30] Link to report: https://haas.berkeley.edu/wp-content/uploads/5g-mobile-impact-on-the-health-care-sector.pdf
[31] Link to report: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7136105/
[32] Link to report: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8764898/
[33] Link to report: https://healthtechmagazine.net/article/2020/11/what-does-future-hold-ar-and-vr-healthcare
[34] Link to report: https://healthmanagement.org/c/healthmanagement/issuearticle/autonomous-delivery-of-medical-material-through-drones-in-a-future-pandemic#:~:text=A%20drone-based%20delivery%20system%20could%20connect%20mobile%20clinics.of%20drone%20systems%20has%20to%20be%20carefully%20monitored.

readiness and functional status of equipment and devices. Additionally, the hospital equipment management system gathers other parameters such as localization of equipment and devices, intrahospital mobility and usage rates.[35] 9. **Interactive smart pharmaceuticals** promote medication compliance. Smart inhalers or insulin pens and similar devices equipped with embedded subscriber identity modules (eSIM) can record their application. Additionally, these devices might implement sensors and algorithmic functions to estimate the effect of a medication on the patient and predict critical situations. These devices may also support personalized medication dose management and precision medication.[36] 10. **Digital twin** enables location-independent patient assessment by retrieving patient data from different repositories, including ad hoc retrieval and volume rendering of extensive image volume data, as well as bidirectional communication for dynamic and interactive research of dedicated aspects on remote devices.[37] 11. **Distributed AI** enables services for personalized medicine by leveraging AI and patient data algorithms to provide personalized treatment. [38] 12. **Tele-assistance and telecare** allow healthcare operators to provide service to individuals in logistically challenging areas, particularly remote/rural areas. 5G-based, hands-free augmented reality technology has a strong potential for remote and medical consultations in real-time under hygienic conditions.[39]	
Potential Operational Benefits	**Potential ESG Benefits**
1. **Facilitate a transition from volume-based fee-for-service models of medical delivery to outcome-based models** with the support of superior health informatics. 2. **Decrease medication and medical errors** while simultaneously increasing medication compliance with enhanced informatics and interactive smart pharmaceuticals. 3. **Train new surgeons or guide a surgeon in a remote area through a complex operation in real-time** with the support of high-resolution image feeds from operating room cameras. 4. **Allow physicians and researchers to access aggregated information and accumulated**	1. **Delivery of healthcare services to rural and underserved communities** which have poor access to healthcare; Doctors, especially specialists, have limited areas in which they practice, but by using telemedicine, primary care doctors on-location can consult with specialists anywhere in the world. 5G enables safe, secure and state-of-the-art telesurgery. [U.N. SDG - 1, 2, 5, 8, 10 and 14] 2. **Decrease medical waste, energy use and, thereby, GHG emissions** with better supply chain forecasting, more efficient facilities and equipment maintenance, and climate controls. [U.N. SDG - 12]

[35] Link to report: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf
[36] Link to report: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf
[37] Link to report: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf
[38] Link to report: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf
[39] Link to report: https://5g-health.org/wp-content/uploads/2020/11/5G-Health-Whitepaper-V1.pdf

knowledge on the latest evidence, diagnosis, and treatment trends through the transfer of high-resolution scans, tests and data-heavy files instantly using cloud-based solutions like Share XR. This creation and rapid movement of data, combined with predictive analytics and machine learning, will not only advance the state of medicine and health outcomes but our understanding of the human condition itself. 5. **Save money for hospitals and healthcare facilities by** helping medical practitioners work from home for some tasks; This frees up facility office space, provides access to doctors and nurses who work outside of the area, and facilitates online training and collaboration opportunities. 6. **Reduce costs through higher usage, lower downtime and more effective and efficient equipment maintenance** through real-time monitoring and diagnoses of hospital equipment and devices. 7. **Eliminate some human steps** by delivering medicine to the bedside of a patient from the pharmacy with the help of small indoor drones. This would lead to more rapid and less error-prone administration of medications. Nurses and pharmacists can work more efficiently as supplies can be summoned to the bedside instead of the time-consuming task of gathering necessary items. Drones could also deliver medications and supplies to patients being cared for in the home instead of in a hospital-based setting. The future will see more outpatient care and even home-based care that used to be delivered in the hospital. For many conditions, drone technology may make it easier and safer to provide this home-based care.	3. **Improved worker health and safety** by using robots and drones for tasks where human involvement may be tedious or dangerous. [U.N. SDG - 3] 4. **Shift of skills** and access to better professional jobs; empower patients, informal carers and lesser qualified professionals; in-field AR support for e-learning and expert advice in remote areas. [U.N. SDG - 8] 5. **Improved patient outcomes and satisfaction while potentially reducing readmissions** by interlinking health and social care and engaging care in proactive healthcare and wellness. [U.N. SDG - 3] 6. **Increased transparency of data, treatment and decisions** (access, audit trail, better reporting of data security, third party access); ability to restrict information to needs. [U.N. SDG - 3]
Estimated Economic Benefits	**Example Metrics Potentially Impacted by 5G**
1. 5G applications in healthcare could add an estimated US$530 billion[40] to global GDP by 2030.	1. Access to the 5G network 2. Number of 5G-enabled digital solutions implemented 3. Estimated total value realized from 5G enabled digital solutions implemented 4. Decrease in patient wait times 5. Decrease in the number of mistake events 6. Decrease in readmission rate 7. Decrease in medication errors 8. Decrease in the rate of complications 9. Decrease in the post-procedural death rate 10. Decrease in the average length of stay 11. Increase in bed/room turnover 12. Decrease discharge process time

[40] Link to report: https://www.pwc.com/gx/en/tmt/5g/global-economic-impact-5g.pdf

	13. Increase in equipment utilization rate 14. Decrease in equipment maintenance costs 15. Decrease in response times for patient transport services 16. Increase in patient confidentiality 17. Decrease in energy usage 18. Decrease in average cost per discharge 19. Decrease in average treatment cost 20. Decrease in the number of patient complaints filed 21. Increase in overall patient satisfaction 22. Increase in percentage of medical documents translated 23. Increase in training per department and percentage of employees that find internal training useful 24. Increase in care access to remote/rural areas

Select case studies:

Virtual Reality Training for Healthcare Workers[41]	
Background	▪ A 2017 study of 107 orthopaedic surgeons found that 80% would like to use VR frequently for training and 90% would recommend VR training to their peers. ▪ The Johnson & Johnson Institute has launched a new global VR training programme for surgeons and nurses, with more than 50 sets of VR equipment worldwide. The programme includes three unique VR training modules for orthopaedic surgery: total knee replacement; total hip replacement with direct anterior approach; and hip fracture treatment with a proximal femoral nail.
Improvement areas	▪ 5G mobile broadband capabilities allow for the simulation of a real-world experience in the operating room, including anatomical accuracy, via all the instruments and implants featured in VR training. ▪ VR training is highly scalable and can thus reduce time and resources spent on training overall. ▪ VR training programs reduce the need to travel to receive training.
Economic and societal impacts	▪ VR training provides cost savings for patients due to greater local availability of medical skills. ▪ VR training modules provide advanced skill enhancement for doctors and support staff and drive greater patient outcomes. [U.N. SDG 3] ▪ The acquisition of new professional skills can lead to increased revenue opportunities. ▪ The use of VR reduces carbon emissions due to reduced travel requirements to attend training programmes.
5G capabilities used	▪ eMBB

[41] Link to report: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.

Virtual Reality Training for Healthcare Workers[41]	
CapEx requirements	▪ VR headsets, motion control devices, surgical training tools and digital infrastructure
Maturity timeline	▪ Current state: 4K streaming that ensures faster delivery of training programmes ▪ Short-term: gamification that leads to immersive surgery techniques ▪ Long-term: internet of medical skills for connected surgery equipment

5G-enabled Healthcare Solutions for Hospitals[42]	
Background	▪ Hospitals have rigid demands to improve patient healthcare services. More than 20 new services are expected to enter the new medical ecosystem, and new advanced applications will place higher requirements on communications networks. ▪ Due to inconsistent information system standards between medical institutions and low levels of data integration, clinical information is not shared between departments and hospitals, resulting in low utilization of medical data resources. ▪ The Futian Medical Consortium (FMC), China Mobile, Huawei and other organizations have jointly advanced a variety of 5G smart healthcare projects in Shenzhen since 2019. These projects have been carried out in all medical institutions – seven hospitals and 83 community health centres – across the district.
Improvement areas	▪ 5G technology, along with multi-edge computing and network slicing, has allowed the FMC to utilize a virtual private network that runs on the public network. This solution allows hospitals to quickly scale their services and meet the real-time transmission needs of the large volume of medical devices and applications supported by the network. ▪ Use of 5G-enabled tablets and medical carts allow medical staff to perform ward rounds and other daily routines efficiently and conveniently. ▪ Regionally connected smart emergency carts in community health centres support one-click activation and enable users to request remote rescue guidance from experts in superior institutions. ▪ 5G networks enable ambulances to offer in-hospital-like services such as patient registration and medical record setup. A patient's vital signs and electrocardiogram, as well as the ambulance's location information, can be transmitted to the hospital's emergency command centre in real-time so that hospital staff can be ready before the patient arrives. ▪ 5G-enabled devices allow experts to provide remote consultations anytime and anywhere, thus breaking restrictions in time and location and improving healthcare access for those in more rural regions.

[42] Link to report: https://www.gsma.com/greater-china/wp-content/uploads/2021/02/5G-Use-Cases-for-Vertical-China-2021-EN.pdf.

5G-enabled Healthcare Solutions for Hospitals[42]	
Economic and societal impacts	▪ The telemedicine market was valued at roughly US$80 billion in 2020 and is expected to grow to US$397 billion by 2027.[43] ▪ 5G networks expand medical coverage to rural/remote areas and allow medical personnel and specialists to provide immediate care to patients. [U.N. SDG 3] ▪ Transport of patients is reduced due to the availability of 5G-enabled healthcare services from experts at local satellite facilities. ▪ 5G technology increases capacity for research and innovation. [U.N. SDG 9]
5G capabilities used	▪ eMBB ▪ URLLC ▪ Security critical
CapEx requirements	▪ Backbone connectivity, AI and big data solutions, data analytics applications, robotics and wearables
Maturity timeline	▪ Current state: faster data processing for enhanced remote patient monitoring ▪ Short-term: AR/VR-based healthcare using cloud edge computing ▪ Long-term: internet of medical skills using machine learning and real-time health systems

[43] Link to report: https://www.fortunebusinessinsights.com/industry-reports/telemedicine-market-101067.

A. Glossary of Key Terms

Terms	Definitions
3GPP	The focal point of development for 5G specifications and standards is the Third Generation Partnership Project (3GPP), a consortium made up of seven of the regional telecommunications standards development bodies. 3GPP has hundreds of technical specifications under development for mobile wireless communications, including the air interface/radio access (5G New Radio), the 5G core, and the IoT, among others. 3GPP is also developing standards for networks to interconnect and collaborate with one another. For example, 3GPP's non-public network support is intended to allow private networks optimized for a specific purpose (e.g., an automated manufacturing facility) to co-exist with public carrier networks.
Area traffic capacity	Total traffic throughput served per geographic area, measured as data rate per unit area. Area traffic capacity increases will enable better network performance in densely populated areas. *Category - Massive Internet of Things (Massive IoT).*
Artificial Intelligence	The ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment.
Augmented Reality (AR)	An enhanced version of the real physical world that is achieved through the use of digital visual elements, sound, or other sensory stimuli delivered via technology.
Automation	Describes a wide range of technologies that reduce human intervention in processes. Human intervention is reduced by predetermining decision criteria, sub process relationships, and related actions — and embodying those predeterminations in machines. Automation includes the use of various equipment and control systems such as machinery, processes in factories, boilers, and heat-treating ovens, switching on telephone networks, steering, and stabilization of ships, aircraft, and other applications and vehicles with reduced human intervention. Automation has been achieved by various means including mechanical, hydraulic, pneumatic, electrical, electronic devices, and computers, usually in combination. Complicated systems, such as modern factories, airplanes, and ships typically use all these combined techniques. The benefit of automation includes labor savings, reducing waste, savings in electricity costs, savings in material costs, and improvements to quality, accuracy, and precision.
Backhaul	The portion of the network that comprises the intermediate links between the core network and the small subnetworks at the edge of the network. In the context of a mobile network, the backhaul connects a cell site toward the core network. The two main methods of mobile backhaul implementations are fibre-based backhaul and wireless point-to-point backhaul.
Bandwidth	Is the maximum aggregated system bandwidth. The bandwidth may be supported by single or multiple radio frequency (RF) carriers. The requirement for bandwidth is at least 100 MHz. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Big Data Analytics	The use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes.
Connection density	Total number of connected and/or accessible devices that can be accommodated, measured in devices per unit area. Increased connection density will support customer use where there are a tremendous number of devices, such as in stadiums and warehouses. *Category - Massive Internet of Things (Massive IoT).*
Control plane latency	Control-plane latency refers to the transition time from a most "battery efficient" state (e.g., Idle state) to the start of continuous data transfer (e.g., Active state). The target for control plane latency should be 10ms. *Category - Enhanced Mobile Broadband (eMBB).*
Coverage	Is the uplink and downlink between device and Base Station site (antenna connector(s)) for a data rate of 160bps, where the data rate is observed at the egress/ingress point of the radio protocol stack in uplink and downlink. The target for coverage should be 164dB (decibel). Link budget and/or link level analysis are used as the evaluation methodology. *Category - Massive Internet of Things (Massive IoT).*
Cyber-physical system (CPS)	A computer system in which a mechanism is controlled or monitored by computer-based algorithms. In cyber-physical systems, physical and software components are deeply intertwined and are able to operate on different spatial and temporal scales, exhibit multiple and distinct behavioral modalities, and interact with each other in ways that change with context. CPS involves transdisciplinary approaches, merging theory of cybernetics, mechatronics, design and process science. CPS is also similar to the Internet of Things (IoT), sharing the same basic architecture; nevertheless, CPS presents a higher combination and coordination between physical and computational elements. Examples of CPS include smart grid, autonomous

Terms	Definitions
	automobile systems, medical monitoring, industrial control systems, robotics systems, and automatic pilot avionics.
Digital Twin	A virtual representation that serves as the real-time digital counterpart of a physical object or process. Data collected from sensors connected to a physical device can be used to update the digital twin copy to reflect any changes to the device's current state.
Digitalization	The use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business.
Digitization	the process of converting information into a digital (i.e., computer-readable) format. The result is the representation of an object, image, sound, document, or signal (usually an analog signal) obtained by generating a series of numbers that describe a discrete set of points or samples. The result is called digital representation or, more specifically, a digital image, for the object, and digital form, for the signal. Digitization is of crucial importance to data processing, storage, and transmission, because it "allows information of all kinds in all formats to be carried with the same efficiency and also intermingled".
Energy efficiency	On the device side, the number of bits transmitted or received per unit of energy consumption. On the network side, energy efficiency refers to the quantity of information bits transmitted to or received from users, per unit of energy consumption of the radio access network (RAN), measured in bits per joule. Energy efficiency improvements are critical due to the expected massive increase in data use over time. Category - Massive Internet of Things (Massive IoT).
GSMA	Global System for Mobile Communications, originally Groupe Spécial Mobile, is an industry association representing the interests of mobile operators worldwide, including more than 750 operators and almost 400 companies in the broader mobile ecosystem. GSMA has published hundreds of security guidelines, recommendations, and requirements over the years regarding best practices in mobile security that support real world deployments related to security of devices, networks, interconnect protocols, and services. GSMA's Fraud and Security Group is particularly active, working on 5G security in the context of other interdependent topics such as IoT and roaming.
IEC	International Electrotechnical Commission is an international standards organization that prepares and publishes international standards for all electrical, electronic, and related technologies – collectively known as "electrotechnology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, solar energy, nanotechnology, and marine energy as well as many others. The IEC also manages four global conformity assessment systems that certify whether equipment, systems, or components conform to its international standards. All electro-technologies are covered by IEC Standards, including energy production and distribution, electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and medical technology, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety, and the environment.
IEEE	Institute for Electrical and Electronics Engineers is involved in the creation of many standards, including WiFi and WiMAX standards, as well as other machine communications standards that will change with 5G.
IETF	Internet Engineering Task Force covers specifications related to 5G non-radio network segments.

Terms	Definitions
Industry 4.0	The Fourth Industrial Revolution, 4IR, or Industry 4.0, conceptualizes the current rapid change to technology, industries, and societal patterns and processes due to increasing interconnectivity and smart automation. The term has been used widely in scientific literature, and was popularized by Klaus Schwab in 2015, the World Economic Forum Founder and Executive Chairman. Schwab asserts that the changes seen are more than just improvements to efficiency, but express a significant shift in industrial capitalism. A part of this phase of industrial change is the joining of technologies like artificial intelligence, gene editing, to advanced robotics that blur the lines between the physical, digital, and biological worlds. Throughout this, fundamental shifts are taking place in how the global production and supply network operates through ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large-scale machine-to-machine communication (M2M), and the internet of things (IoT). This integration results in increasing automation, improving communication and self-monitoring, and the use of smart machines that can analyze and diagnose issues without the need for human intervention. It also represents a social, political, and economic shift from the digital age of the late 1990s and early 2000s to an era of embedded connectivity distinguished by the omni-use and commonness of technological use throughout society (e.g., a metaverse) that changes the ways we experience and know the world around us. It posits that we have created and are entering an augmented social reality compared to just the natural senses and industrial ability of humans alone.
Internet of Everything (IoE)	The networked connection of people, process, data, and things. The benefit of IoE is derived from the compound impact of connecting people, process, data, and things, and the value this increased connectedness creates as “everything” comes online.
ISO	International Standards Organization is an international non-governmental organization made up of national standards bodies that develops and publishes a wide range of proprietary, industrial, and commercial standards. In addition to producing standards, ISO also publishes technical reports, technical specifications, publicly available specifications, technical corrigenda, and guides. The ISO plays an important role in facilitating world trade by providing common standards among different countries. ISO standards cover all fields, from healthcare to technology to manufacturing to security to the environment.
ITU	The International Telecommunications Union is in the process of developing ITU-R Recommendations for the terrestrial components of the IMT-2020 radio interface(s) based upon specifications from external, industry-led standards development organizations.
Latency	Time it takes from when the source sends a packet of data to when the destination receives it, usually measured in milliseconds. More precisely, latency for 5G is the contribution by the radio network to this time. Low latency is especially important for applications, such as industrial automation or remote medicine, where delays in data transfers could be disastrous. *Category - Mission Critical Control (MCC).*
Machine Learning	The use and development of computer systems that are able to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and draw inferences from patterns in data.
Mobility	Maximum speed a device can be traveling and still experience a defined quality of service. Mobility is important for applications that require reliable connection when moving, such as in transportation safety. The target for mobility should be 500km/h. *Category - Enhanced Mobile Broadband (eMBB).*
Mobility interruption	Mobility interruption time means the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions. The target for mobility interruption time should be 0ms. This KPI is for both intra-frequency and inter-frequency mobility for intra-New Radio (NR) mobility. *Category - Mission Critical Control (MCC).*
Network energy efficiency	The capability is to minimize the RAN energy consumption while providing a much better area traffic capacity. Both qualitative and quantitative KPIs are proposed. Network energy efficiency shall be considered as a basic principle in the New Radio (NR) design. The target is a design with: (1) the ability to efficiently deliver data; (2) the ability to provide sufficiently granular network discontinuous transmission when there is no data to transmit and network availability is maintained; (3) the ability to provide operator flexibility to adapt sleep durations of base stations depending on load, services, and area. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Operational lifetime	Operation time per stored energy capacity, which is particularly important for Internet of Things (IoT) devices requiring a very long battery life whose regular maintenance is difficult for physical or economic reasons. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*

Terms	Definitions
O-RAN Alliance	Is working to build specifications and standards for 5G networks, focused on open and interoperable interfaces for radio access networks.
Peak data rate	Peak data rate is the highest theoretical data rate, which is the received data bits assuming error-free conditions, assignable to a single mobile station when all assignable radio resources for the corresponding link direction are utilised (i.e., excluding radio resources that are used for physical layer synchronisation, reference signals or pilots, guard bands and guard times). The target for peak data rate should be 20Gbps for downlink (DL) and 10Gbps for uplink (UL). *Category - Enhanced Mobile Broadband (eMBB).*
Peak spectral efficiency	Maximum achievable data rate under ideal conditions, usually measured in gigabits per second (Gbps), that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the medium access control (the channel access protocol). The target for peak spectral efficiency should be 30bps/Hz for downlink (DL) and 15bps/Hz for uplink (UL). Higher frequency bands could have higher bandwidth, but lower spectral efficiency and lower frequency bands could have lower bandwidth but higher spectral efficiency. Thus, peak data rate cannot be directly derived from peak spectral efficiency and bandwidth multiplication. *Category - Enhanced Mobile Broadband (eMBB).*
Price per MHz per unit population	A commonly used metric for expressing prices paid for spectrum during government auctions. Price per MHz per unit population first takes the total price paid by a network provider for a range of spectrum and divides it by the number of MHz purchased. This price per MHz is then divided again by the provider's number of people covered to obtain the final price per MHz per unit population. This metric allows for more accurate comparisons of spectrum prices across different auctions to be made since it accounts for market size.
Reliability	Capability to provide a given service with a very high level of availability. Reliability is compromised if too much data is lost, late, or has errors. Improving the reliability of the network is critical for time-sensitive, mission-critical applications like automation and healthcare. Category - Mission Critical Control (MCC).
Resilience	Ability of the network to continue operating correctly during and after a natural or man-made disturbance, such as the loss of power. Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).
Robotics	An interdisciplinary branch of computer science and engineering. Robotics involves design, construction, operation, and use of robots. The goal of robotics is to design machines that can help and assist humans. Robotics integrates fields of mechanical engineering, electrical engineering, information engineering, mechatronics, electronics, bioengineering, computer engineering, control engineering, software engineering, mathematics, etc. Robotics develops machines that can substitute for humans and replicate human actions. Robots can be used in many situations for many purposes, but today many are used in dangerous environments (including inspection of radioactive materials, bomb detection and deactivation), manufacturing processes, or where humans cannot survive (e.g., in space, underwater, in high heat, and clean up and containment of hazardous materials and radiation).
Security and privacy	Ability to encrypt and protect user data and signaling, and enhance network security against cyberattacks, such as unauthorized user tracking, hacking, fraud, sabotaging, and denial of service, which can be detrimental to national security and the safeguarding and privacy of users' data. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Sensor	A device that produces an output signal for the purpose of sensing of a physical phenomenon. In the broadest definition, a sensor is a device, module, machine, or subsystem that detects events or changes in its environment and sends the information to other electronics, frequently a computer processor. Sensors are always used with other electronics. Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, and in innumerable applications of which most people are never aware. With advances in micromachinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the traditional fields of temperature, pressure, and flow measurement, for example into MARG sensors. Analog sensors such as potentiometers and force-sensing resistors are still widely used. Their applications include manufacturing and machinery, airplanes and aerospace, cars, medicine, robotics, and many other aspects of our day-to-day life. There is a wide range of other sensors that measure chemical and physical properties of materials, including optical sensors for refractive index measurement, vibrational sensors for fluid viscosity measurement, and electro-chemical sensors for monitoring pH of fluids.

Terms	Definitions
Spectrum	The ranges of frequencies (or airwaves) on the electromagnetic spectrum that are allocated to the mobile industry and other sectors for wireless communication. Spectrum is a sovereign asset, which implies that the use of such airwaves is overseen by the government or national regulator, who manages and issues licenses to permit usage.
Spectrum and bandwidth flexibility	Flexibility of the network design to handle 5G Wireless different scenarios, such as the capability to operate at different frequency ranges. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
UE energy efficiency	Is the capability of a UE to sustain much better mobile broadband data rate while minimizing the UE modem energy consumption. *Category - Massive Internet of Things (Massive IoT).*
User Equipment (UE) battery life	Is the battery life of the UE without recharge. For mMTC, UE battery life in extreme coverage shall be based on the activity of mobile originated data transfer consisting of 200bytes UL per day followed by 20bytes DL from MaxCL of 164dB, assuming a stored energy capacity of 5Wh. *Category - Massive Internet of Things (Massive IoT).*
User plane latency	Is also known as the radio segment latency. It is the one-way latency for successful reception of a packet and includes the time for one or more retransmissions if packet reception fails. The target for user plane latency should be 0.5ms for upload (UL), and 0.5ms for download (DL). Furthermore, if possible, the latency should also be low enough to support the use of the next generation access technologies as a wireless transport technology that can be used within the next generation access architecture. For eMBB, the target for user plane latency should be 4ms for UL, and 4ms for DL. *Category - Enhanced Mobile Broadband (eMBB).*
User-experienced data rate	User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e., the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time. The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment: (1) Downlink user experienced data rate is 100 Mbit/s; (2) Uplink user experienced data rate is 50 Mbit/s. *Category - Enhanced Mobile Broadband (eMBB)*
Virtual Reality	The use of computer technology to create a simulated environment which can be explored in 360 degrees. Unlike traditional interfaces, VR places the user inside the virtual environment to give an immersive experience.