DIGITAL TWIN STATE OF PRACTICE REPORT:

ADVANCED CANADIAN MANUFACTURING NGEN DIGITAL TWIN ADVISORY BOARD

NGen Next Generation Manufacturing Canada

December, 2021

Table of Contents

CEO Remarks

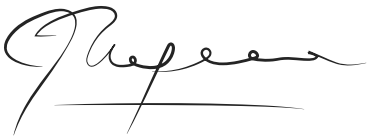
Next Generation Manufacturing Canada is dedicated to building world leading advanced manufacturing capabilities in Canada. An important part of what we do in pursuit of that objective is enhancing the capacity of Canadian manufacturers to adopt and deploy advanced technologies in a productive and profitable way. The challenge is particularly relevant for SMEs which account for 95% of all manufacturing companies across the country.

NGen's Tech Adoption Advisory Groups play a leading role in helping us achieve our goal. They bring researchers and industry specialists together from across Canada to map out our technology capabilities, assess the challenges and opportunities involved in expanding and accelerating the successful adoption of key Industry 4.0 technologies in Canadian manufacturing, and propose an action plan for further collaborative efforts to strengthen Canada's advanced manufacturing sector. This report on behalf of the Digital Twin Advisory Group makes an important contribution to our understanding of the potential of deploying cyber-physical systems in manufacturing and what we can do to help realize the future opportunities that may result.

Digital twins – virtual equivalents of real-world systems and objects – are powerful tools that allow manufacturers to design, monitor, simulate, test, and control products and processes in real time. They are revolutionizing every aspect of product life cycle management – from design and product development, to manufacturing, service, operation, maintenance, and disposal. They are providing manufacturers the opportunity to understand, predict, and solve operating problems more rapidly and comprehensively than ever before. And, by integrating both customers and suppliers, digital twins are enabling a far greater degree of customer satisfaction and value chain alignment and efficiency, key requirements for sustaining competitiveness and business growth.

However, as this report also points out, the level of awareness about digital twin technologies and the preparedness of companies to deploy them successfully to improve performance is relatively low among Canadian manufacturers. There is a lot that can be done – collaboratively – to educate Canadian manufacturers, pilot and highlight use cases, assist in data management and training, and point them towards the technology and service providers that can help them along the road to using digital twins productively in their business.

I want to thank the members of the Advisory Group for the time and effort they have committed and the advice they have provided in this report. It provides a solid action plan for NGen going forward.



Jayson Myers
Chief Executive Officer
NGen Canada

Background

NGen is the industry-led, not-for-profit organization leading Canada's Advanced Manufacturing Supercluster. One of five national networks supported by Canada's ambitious Innovation Superclusters Initiative, NGen is founded on the principle that digital transformation in advanced manufacturing will enrich the lives of Canadians, delivering better products and good jobs while generating the economic growth essential to a better future.

NGen has developed focus groups of key technologies intending to support the digital transformation of Canadian Manufacturers by helping them with adopting key enabling technologies. The mission of these Tech Adoption groups is to build communities of practice, enable organizations to establish collaborations and partnerships, help Canadian SME Manufacturers to learn about best practices, industry benchmarks and to share lessons learned.

Tech Adoption focus groups for Additive Manufacturing, Automation and Robotics, Machine Learning and Digital Twins are all under development currently, with a fifth about to be launched. All NGen Tech Adoption focus groups are led by Advisory Boards.

Volunteers from the NGen membership serve on the Digital Twin - Technology Adoption Advisory Board. Members of this advisory board assist and guide NGen personnel in identifying gaps in available resources and roadblocks to adoption of the technology by Canadian manufacturers, along with recommendations for solutions to those gaps and roadblocks. The Advisory Board is also responsible for reviewing and releasing this White Paper describing the scope of digital twins and the state of practice of the use of Digital Twins in Canada.

Figure 1: Forces accelerating the switch to Electric Mobility | www.stambol.com/2018/07/02/digital-twins-doing-real-world-work

Executive Summary

Organizations across Canada have different understandings of exactly what a digital twin is. This report provides a description of digital twin applications across multiple sectors and proposes a definition of digital twin that the members of the Advisory Board believe will be the most helpful to the Canadian SME Manufacturing ecosystem. Industry 4.0 and Digital Twins are relatively new descriptions, but well before these terms became common, Canadian manufacturers had benefited from adopting CAD/CAM, digital technologies, and automated process control systems. Further investments into models and simulation have also proliferated throughout the world and across Canada. By allowing problems to be identified and addressed during the conceptual and design stages of product development, modeling and simulating have saved $Bs for manufacturers, as well as having shortened the product development cycle. Digitization of various manufacturing processes enables businesses to adapt quickly and remain competitive on the world stage. Manufacturers using Digital Twins expect benefits of improved quality, maintenance based on actual needs (rather than time-schedules) and reduced operational costs (energy, waste, and time).

What are they and why are they important?

The idea of digital twin technology was first voiced in 1991, with the publication of Mirror Worlds, by David Gelernter. However, Dr. Michael Grieves (then on faculty at the University of Michigan) is credited with first applying the concept of digital twins to manufacturing in 2002 and formally announcing the digital twin software concept. Eventually, NASA's John Vickers introduced a new term – "digital twin"– in 2010.

– What is a Digital Twin, IBM

What is a Digital Twin (vs. Digital Model and Digital Shadow)?

A Digital Twin is an application of technologies that includes connections between both physical and virtual elements. The connections of real-time data capture and closed-loop feedback are coupled with simulation (and models) to optimize operational performance.

The digital twin is a virtual replica of the physical device, both are connected, and can be synchronized via the data flow. There has been some confusion about exactly what a Digital Twin is. Figure 2 below is illustrative of the difference between a Digital Model, a Digital Shadow and a Digital Twin and establishes the definition of the term Digital Twin that is used throughout this report. As with many advancements based on digital technologies, the potential applications of the Digital Twin concept are diverse.

Digital Model
A digital representation of an existing or planned physical object that does not use any form of automated data exchange between the physical object and the digital object. Digital data of existing physical systems might still be in use for the development of such models, but all data exchange is done in a manual way. A change in state of the physical object has no direct effect on the digital object and vice versa.

Digital Shadow
Based on the definition of a Digital Model, if there further exists an automated one-way data flow between the state of an existing physical object and a digital object, one might refer to such a combination as Digital Shadow. A change in state of the physical object leads to a change of state in the digital object, but not vice versa.

Digital Twin
If further, the data flows between an existing physical object and a digital object are fully integrated in both directions, one might refer to it as Digital Twin. In such a combination, the digital object might also act as controlling instance of the physical object. There might also be other objects, physical or digital, which induce changes of state in the digital object. A change in state of the physical object directly leads to a change in state of the digital object and vice versa.

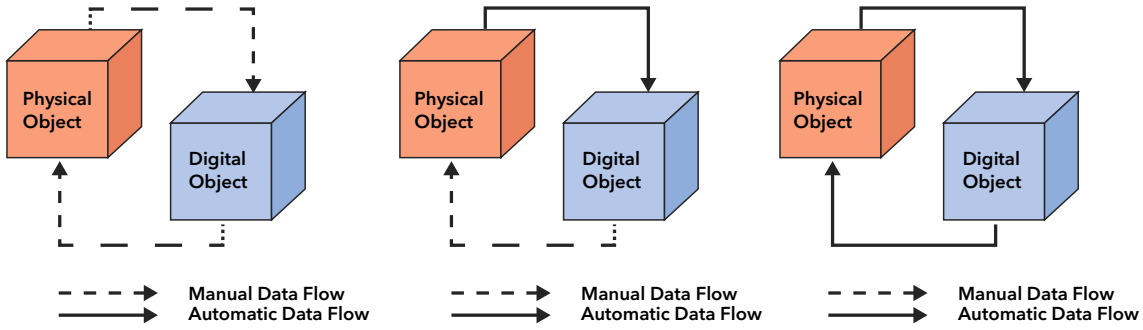


Figure 2: A definition of a Digital Twin and the evolution of Digital Twins from Digital Models (Kritzinger, Karner, Traar, Henjes,, & Sihn, 2018)

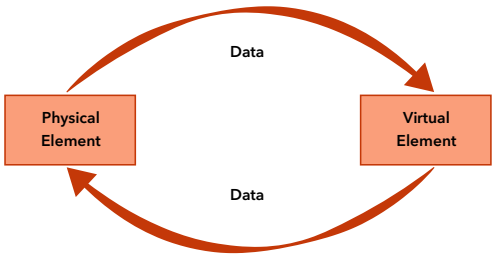
Physical Element

The Physical Element of a Digital Twin is instrumented to generate live, operational data which is sent to the Virtual Element of the DT. Thanks to the wide variety of available types of sensors, Digital Twin technology has the potential to benefit a wide array of physical elements (devices, networks of devices, systems, etc.). For example, the human body can be connected to a Fitbit-like device or to a defibrillator. An automobile or an office building could also be the physical element in a digital twin that may be modeled and for which real-time feedback could provide measureable benefit (reduced maintenance, for example). This document will focus on the application of digital twins for manufacturing, however the technology has the potential to be widely transformative, and its application will likely become widespread. The Physical Element of a DT for a manufacturing application may consist of a production machine, manufacturing line, product cell, or product realization system or an entire value chain.

Virtual Element

For years, CAD/CAM models have been used to design products that are eventually physically manufactured. This virtual representation of a physical element (or device) is part of the physical-virtual system that makes up a digital twin, but not, in and of itself, a digital twin.

The Virtual Element exists in a computing space and contains a digital representation of the Physical Element which incorporates the ability to provide and utilize two-way feedback to and from the Physical Element. The Data provided by the Physical Element may provide, for example, actual real-time operational information back to the Virtual Element. Comparisons between ideal operations and actual operations may then be made within the virtual environment.



Recommendations of changes for optimal performance could be computed in the Virtual Element, and those changes sent back (in the form of control data), to the Physical Element.

The Fundamental Role of Simulation

The core of a Digital Twin is the simulation capability embedded within the digital model of the physical device. Sometimes multiple models are connected to the simulator, representing a larger system with multiple physical elements. Benefits of connecting the two data paths (monitoring and control) between the Physical Devices and the Virtual Environment (Digital Twins) may include improved operational efficiency, improved quality, lower maintenance costs, greater safety, longer product life and automated updates to supply chains.

A typical purpose of a digital twin simulation on the manufacturing floor is to provide a closed loop in support of real-time monitoring and control of a machine tool. However, once the models and simulations have satisfied the primary purpose (of real-time monitoring/control on the shopfloor), there are other potential benefits. For example, an off-line (not connected live) version of the digital twin simulator offers great potential for testing and evaluating potential process improvements. Product development iterations and operational scenarios may be run in a fully representative virtual simulation environment quickly and at low cost. In this way, optimum configurations may be rapidly defined.

Making changes in the virtual environment is much less costly and much quicker to evaluate than making similar changes in the physical space. Modeling and simulation improve time-to-market while reducing risks and costs. As models improve, become more granular (higher fidelity) and are better coupled with simulators, the virtual environment will evolve to support the types of "what-if" scenario assessments that will provide enterprise-wide benefits.

Digital Twin vs. SCADA and HMI

SCADA (Supervisory Control and Data Acquisition) and HMI (Human Machine Interface) commonly used to interact with equipment provide an automated one-way communication from the physical object to a digital object. Similarly, closed loop control systems provide fully integrated data flows in both directions. This does not mean that a SCADA/HMI system is a "Digital Shadow" nor a closed loop control system a "Digital Twin". What sets the Digital Shadow and the Digital Twin apart from SCADA/HMI and closed loop control systems is the use of simulation. A simulation that represents the physical, chemical, biological, or biochemical behavior of the physical object. To quote Dr. Michael Grieves - "At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin"

Digital Twin Categories

The advancement and proliferation of high-speed digital communication networks across the world over the past few decades has accelerated the application and benefits of digital technologies in manufacturing and multiple other sectors. Digital manipulation (simulation), which uses operational data, has also been enabled by the fact that it has become very affordable to capture digital data in real-time. The combined factors of high-speed digital connectivity, the relatively low cost of capturing real-time data and the availability of the necessary processing power to support digital simulation in-house or over the web have been leveraged by industry leaders in many categories and sectors as described in the Types of Digital Twins (below) to great benefit.

Digital Twins by Sector

- Manufacturing: Digital Twins are poised to change the current face of the manufacturing sector. Digital Twins have a significant impact on the way products are designed, manufactured and maintained. The combined abilities to virtualize production systems and manage production flows in real-time make manufacturing more efficient and optimized while increasing throughputs.

- Automotive: Digital Twins can be used in the automotive sector to create a virtual representation of a connected vehicle. This representation can capture the mechanical and operational performance of the vehicle as well as the subjective driver experience and support analyses of the overall vehicle performance as well as that of connected features. It also offers the potential to deliver a truly personalized/ bespoke service to each customer.

- Retail: Providing an appealing customer experience is key in the retail sector. Digital twin implementations can play a key role in augmenting the retail customer experience in many different ways. One example is in creating a virtual twin of a customer to enable them to see what a given piece of clothing or pair of glasses would look like on them. Digital Twins also help in better in-store planning, security monitoring and optimized energy management.

- Healthcare: Digital Twins along with data from IoT can play a key role in the health care sector from cost savings to patient monitoring, preventative maintenance and providing personalized health care.

- Smart Cities: The use of Digital Twins in smart city planning and implementation enhances economic development, supports efficient management of resources including the reduction of ecological footprint and has the potential to improve the overall quality of each citizen's life. The digital twin model can help city planners and policymakers in smart city planning by providing insights and data from various sensor networks and intelligent systems. The data from the digital twins can not only help planners in arriving at informed decisions regarding city operations today, but also provides guidance for the smart cities of the future.

- Industrial IoT: Industrial firms with digital twin implementations can now monitor, track and control industrial systems digitally. Apart from the operational data, the digital twins capture environmental data such as location, configuration, financial models etc. which helps in predicting future operations and rapidly identifying any anomalies.

What is Digital Twin Concept | Applications – Happiest Minds

Non-Manufacturing Explanation of Digital Twins

Digital Twin is an application of technologies that includes connections between physical and virtual elements coupled with simulation, real-time data capture and closed-loop feedback.

The Digital Twin is a virtual equivalent of a real-world system or an object. The Digital Twin represents the dynamic behaviour regarding how a physical element, a device or other system, operates and works through its life cycle. A digital twin is based on a set of models that describe a product, a system, a person, an infrastructure, or a process. A digital twin is a linked collection of virtualisations, including high fidelity simulation, design data, engineering data, operational and behavioural descriptions. A Digital Twin is a logical construct, meaning that the actual data and information may be contained in other applications.

The Digital Twin

- Evolves as it is updated through the life cycle.
- Is an abstraction of the past and currently available digital data that are gathered to feed the digital models.
- Is an open concept. Data and models can be added at any time. As the content of the digital twin becomes validated, the obsolete data and/or models are removed.
- Is updated with real life data and uses simulation and machine learning to help with decision making. It is intended to be an up-to-date and accurate copy of the physical object's properties and states, including shape, position, gesture, status, and motion.
- Data from the real system is synchronised with the digital twin to represent the current state of the system. Based on the actual and previous data, prediction of future behaviour of the system in response to these provided inputs becomes possible.

Digital Twins in Manufacturing: A Roadmap to Implementation

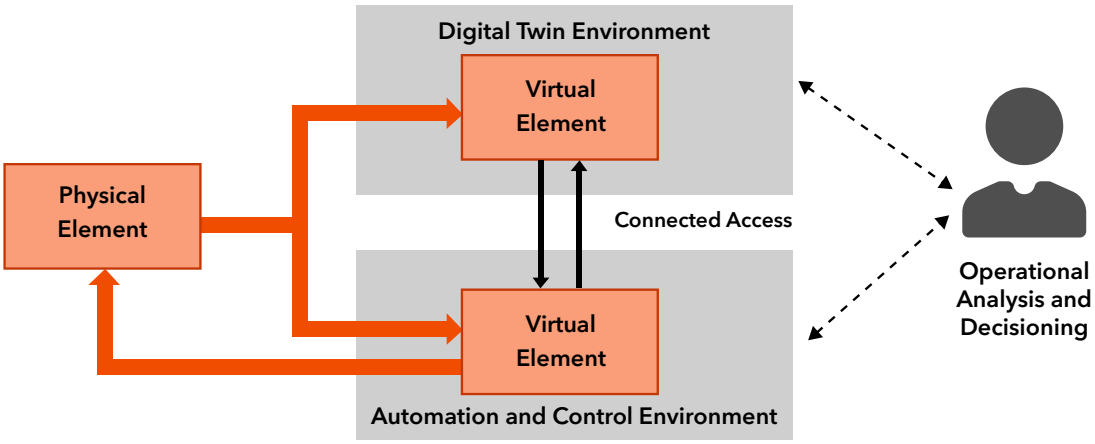
How Digital Twins are operationalized and interact with users

Digital Twins operate in a Digital Twin Environment. The environment is an operating system/computing environment where the code for virtual element (simulations and models that mathematically represent the physical element) can be continuously executed and kept up to date with new information about the physical object. The environment also provides the means for the Digital Twin to communicate with the real-time signals from the physical element using API's (Application programming interface) or industry specific protocols.

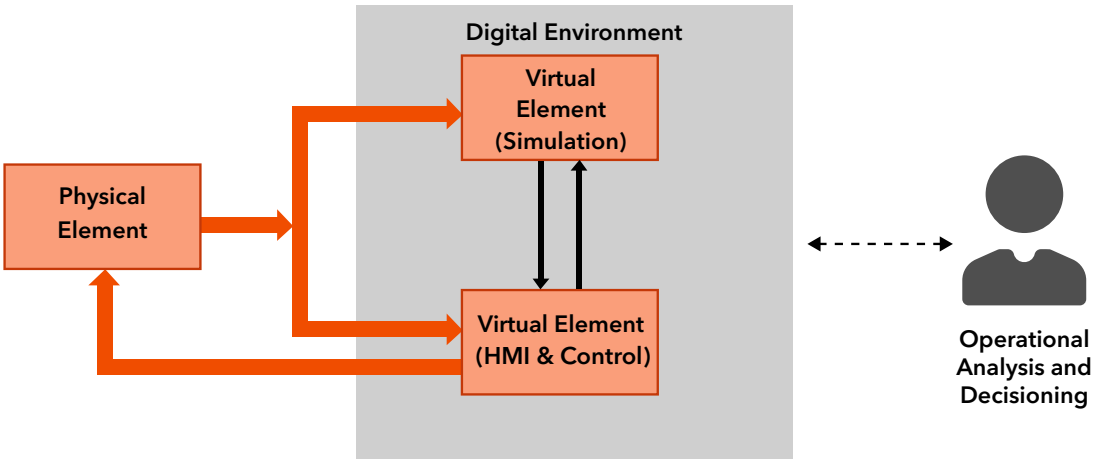
The Digital Twin environment may be created in the cloud or on-premises (with physical computing hardware).

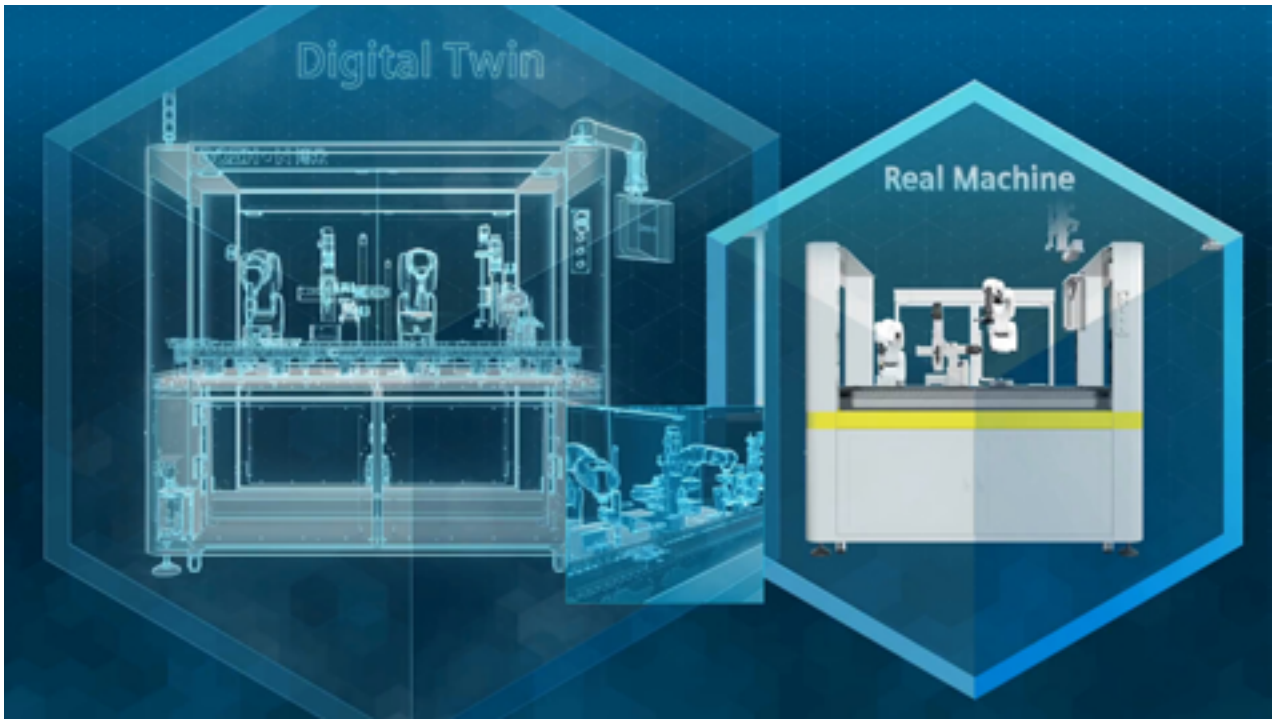
In manufacturing applications, the current state of the physical element (a machine, cell, line or an entire factory) is communicated to systems used to run the physical equipment – such as SCADA and HMI's or closed loop control systems (Automation and Control). It is therefore common for the DT to communicate with the physical element via such existing systems so that separate communication between the DT and the physical element does not have to be created. The DT can also provide commands and control to change the state of the physical element via these systems.

The DT environment may be different from the Automation and Control environment. This is typical when deploying DT at legacy facilities with existing automation and control systems (see diagram below).



In newer deployments, the DT may share a common environment with existing automation and control systems (see diagram below)





www.plm.automation.siemens.com/global/en/webinar/digital-twin-in-manufacturing/68561

Scaling Digital Twins

Once machine-based Digital Twins are implemented on a shopfloor and the benefits measured in real time (local cell), further adoption can be planned with support from all stakeholders in the business. Migration from machine-based Digital Twins to entire manufacturing lines and complete manufacturing plants becomes possible. Even virtual commissioning can be (eventually) derived with this strategy. Oftentimes these grand strategies have been captured in use-cases and published by MNE Manufacturers. The projected benefits are tremendous. The use-cases are well documented however the overall description of Digital Twins that enable these grand benefits are much beyond the application and scope of an SME in Canadian Manufacturing.

Example applications: Manufacturing

- Product development
- Design customization
- Performance improvement
- Process planning and optimization
- Quality management
- Supply Chain Management
- Predictive Maintenance
- Cross-Discipline Collaboration
- Analyze the Customer Experience
- Optimizing warehouse design and operational performance
- Operation management
- Virtual testing
- Training
- Space optimization
- System integration
- Diagnostics
- Prediction

- Real-time sharing of information
- Improving safety
- Removing risks from experimentation
- Providing missing input for databases
- Simulating Complex Manufacturing Scenarios
- Optimizing Traffic Flows
- Interoperability
- Visualization
- Malfunction detection and prediction
- Disaster management
- Operational Analysis
- Improve ROI

Complex Systems and Digital Twins

Control systems in industrial facilities rely on proportional-integral-derivative (PID) controllers that perform satisfactorily in many applications but do not provide "optimal control". The fundamental difficulty with PID control is that it is a feedback control system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise relative to the potential of a true digital twin.

In comparison, digital twins provide an opportunity to define physics-based models that adapt to conditions observed in the real-world and can utilize the control channel to optimize the manufacturing process, thereby providing the manufacturer with the best control performance.

Quoting Dr. Michael Grieves: "Digital Twin (DT) - the Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. Digital Twins are of two types: Digital Twin Prototype (DTP) and Digital Twin Instance (DTI). DT's are operated on in a Digital Twin Environment (DTE)"

Digital Twin Adoption Strategies

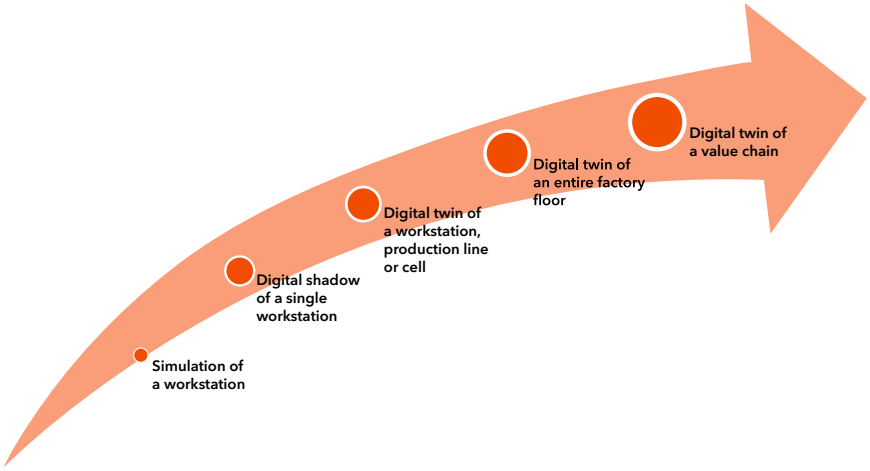
Many people have years of experience with versions of digital technology integration into the CAD/CAM workplace. As a result, directly connecting the Physical Asset to the Digital Asset provides a relatively new, but immediately understood approach to optimizing a manufacturing process.

Many experienced manufacturing people (engineering/admin/executives) have benefited from reading a description of the differences between Digital Model, Digital Shadow, and Digital Twin. That description is included above (in Figure 2) for the benefit of readers who may wish to better understand some of the technical details.

One adoption strategy could be for companies to start moving towards digital twins by first adopting digital models, then digital shadows and finally create a digital twin of their environment. Over time, expectations are that digital twins may be effectively used to model an entire production facility or even an entire value chain. A gradual implementation approach would provide incremental success and reduce the risk of disillusionment that some of the more transformative elements of Industry 4.0 face when the challenges of successful implementation are poorly understood (and that delay their adoption).

The readers of this report may benefit from the descriptions of Digital Twins in the context of global

sectors; however, these readers are expected to focus on SME adoption of Digital Twins in Canadian manufacturing. This report assumes the reader is an SME manufacturer looking to adopt Digital Twins or at least investigate the technology. That reader may start their application of Digital Twin technology in application to a single machine on their production floor, before considering wider adoption to manufacturing lines, manufacturing plants or the broader value chain (potentially in conjunction with customers and suppliers). This report has been created for this specific audience.



NGen Digital Twins Advisory Board

NGen has developed focus groups of key technologies intending to support the digital transformation of Canadian Manufacturers by helping them with adopting key enabling technologies. The Tech Adoption focus group for Digital Twins was formed and the members of the NGen Tech Adoption Advisory Board, identified in the table below. Adoption of Digital Twins in Canadian Manufacturing is relatively low, particularly amongst SMEs. Typical implementations loosely following the digital twin architecture described above, without classifying the implementation as a Digital Twin. Large infrastructure installations have invested significant resources to create Digital Twins and often publish case-studies as testimonials to the benefits of adopting Digital Twin technology.

Volunteers from the NGen membership serve on the Digital Twin - Technology Adoption Advisory Board. Members of this advisory board assisted and guided NGen personnel in identifying gaps of resources and roadblocks to adoption of the technology by Canadian manufacturers, along with recommendations for solutions to those gaps and roadblocks. The Advisory Board members replied to surveys and conducted phone calls to fulfill the responsibility for reviewing and releasing this White Paper describing the scope of digital twins and the state of practice of the use of Digital Twins in Canada.

Digital Twin Advisory Board Members

The members of the NGen Digital Twin Advisory Board are focussed on the adoption of Digital Twins in the Manufacturing sector, with the specific focus of enabling SMEs to evaluate the technology and (wherever warranted) to implement Digital Twins most efficiently.

Digital Twins Advisory Board Members

Company	Member	Title
Demtool Inc.	Andrew Dekker	Operations Mgr
Mosaic Manufacturing	Derek Vogt	CTO and Founder
Mycionics	Michael Curry	CEO
Tactile Robotics	Yaser Maddahi	President & CEO
ReDeTec	Ben Robertson	CTO
LabsCubed	Jeff Petracca	COO
G2V	John Walmsley	VP Product Development
Agyle Intelligence Solutions	David McNally	CEO
Area52	Tim Fogarty	Founder
BI Expertise	Hobivola A. Rabearivelo	Chief Strategy
KPI Digital	Nicole Whittle	VP App Dev
KPI Digital	Richard Langlois	VP Data, Analytics
Empower Operations	Gary Wang	CEO
EXO Insights	Fernando Muniz-Simas	CEO
Panevo Services Limited	Thomas Tartiere	Lead SW
Kepstrum	Payman Kianpour	Director
Eigen Innovations	Scott Everett	CEO
SHEA Solutions Inc.	Jeffrey Hunt	CEO
Quartic.ai Canada, Inc.	Rajiv Anand	President & CEO
ProSensus	Marlene Cardin	Dir Projects
Cast Analytics Inc.	Carl Reilly	CEO
Cheme Engineering Inc	Chris Defina	Principle Eng
IFIVEO Canada Inc.	Khizer Hayat	CTO
Mazlite Inc.	Amirreza Amighi	CEO
Long View Systems Inc.	Nolan Evans	VP Ontario
Standards Council of Canada	Edwin Ndatuje	DT SCC lead
Pegasus Research & Tech	Kevin Heffner	President
CRVI Robotique Vision	Mathieu Goulet	Project Manager

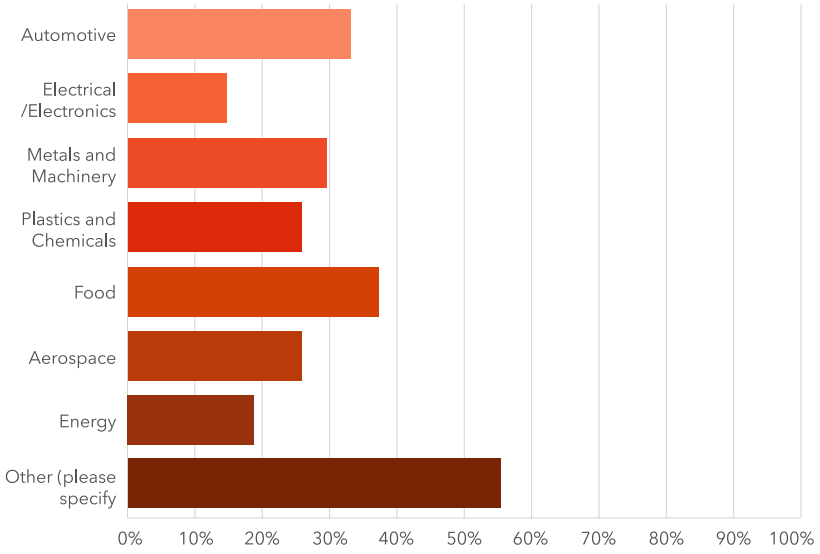
Survey Results - Digital Twin Adoption Priorities – for Canadian SME Manufacturers

The Next Generation Manufacturing Canada team developed a survey to assess the state of adoption for Digital Twin technologies across Canada. The members of the advisory board completed this survey, which is provided as Appendix A to this report.

Some results of the survey are summarized below:

Q2. What is your principal market?
The profile of membership for the Digital Twin Advisory Board seems well suited to heighten awareness across multiple business sectors with the distributed sector of membership.

Q2. What are your main customer/client market(s)?



Q5. Do you think Canadian companies are well informed about the business case for Digital Twins?
The survey results indicated that there is a very low awareness of the potential business benefits of Digital Twins in manufacturing. Comments indicate that part of the problem is that there is not a common understanding of exactly what a Digital Twin is. This report has attempted to explain the adoption of digital twins for manufacturing applications out of the list of global applications which includes Manufacturing, Automobile, Retail, Healthcare, Smart Cities and Industrial IoT. It is hoped that this overview will help address this gap.

Survey respondents indicated that NGen (and the Digital Twin Advisory Board) could provide learning methods or tools to help companies to develop Digital Twin skills and supporting business cases. One recommendation was that a working group could be formed to determine the best way to improve these skills and the associated value proposition.

Q6. Awareness - What is a digital twin?

This report has attempted to explain what a digital twin is, how they can be applied in various industries and capacities and, more specifically, how they are being used in manufacturing.

Awareness is the one weakness that most greatly affects Digital Twin adoption in Canada (according to 100% of survey respondents).

Q6. How could awareness about Digital Twins be improved in Canada?

awareness etc use cases definition benefits people
education need DT provide used DTs examples
Case studies digital twin workshops

Awareness of the effectiveness of Digital Twins can be brought to the attention of the Canadian SME Manufacturing ecosystem by Use Cases and Education. Some members have expressed interest and committed time to improving awareness by contributing to the Digital Twin Working Groups.

Q12. What existing investments of digitization can be leveraged by Canadian SMEs for Digital Twin Integration?

Canadian SME Manufacturers have invested in Digital Technologies. A key benefit of this investment in digitization is that these investments are reusable, from one product to the next, from one production line to the next. Leveraging some of these existing Digital assets, may reduce the integration costs of Digital Twins or improve the fidelity of existing CAD-based simulations. One of the key challenges for a Technology Adoption Group in support of the application of Digital Twins in manufacturing then becomes building awareness of the technology and how it builds on other elements of Industry 4.0 that may already be in place at Canadian manufacturers.

Q12. What existing investments of digitization can be leveraged, by Canadian SMEs for Digital Twin Integration? (Existing investments of digitization could include simulations, models, AR/VR training, process management, supply chain management, and other digital assets)

also leverage technologies digital twins models
process management data control simulations VR AR existing
supply chain managment cloud

The most common response of the members of the advisory board was that there needs to be more information regarding how the data and models currently in wide use can be leveraged into Digital Twins.

Q14. Can NGen help improve Digital Twin skill, and if so, how?

A major focus of NGen's ecosystem building activities is associated with working with established Colleges, Universities, and Industry-based training providers to develop the curricula, courses and mi-

cro-credentials needed to support the wide adoption of Industry 4.0 technologies by Canadian manufacturers.

Q14. Can NGen help improve Digital Twin skills, if so how?

Potential risks/issues

Software development could be a new discipline for SME Manufacturers. One comment from an Advisory Board member was that manufacturers were new to the software development experience and expected systems to operate once and always without fail, never needing to be updated or fixed. This could be a key training need for manufacturers to successfully adopt this technology.

Another takeaway from the survey was that there are some new risks to manufacturers in adopting Digital Twins in respect of integration and cyber-security. Some of these findings are summarized below.

- The responsibility of an IT department typically deals with business networks and software, while anything on the OT side falls under the responsibility of the operational team in an industrial facility. This traditional assignment of responsibility means that companies may need to take a different approach to the implementation of DT technologies to bridge these traditionally separate functions. Successful implementation of this technology thus requires a cross-functional team that has the skills and level of authority to operate across operations and IT. The challenge is exacerbated if one of the other function is handled by an outside contractor.

- IT security policies may not have been designed to protect modern IoT projects. And digital twin implementations may require a change in the concept of security across both IT & OT models. An adjustment of the security policies becomes necessary, particularly in the context of emerging cyber-threats.

The advisory board made a series of recommendations for the work of the NGen supported Technology Adoption Cluster for Digital Twins.

Recommendation 1 – Need for high quality use cases with supporting data

Larger $100M+ operations are much more knowledgeable about the benefits of specific digital technologies including Digital Twins because they have the resources to investigate and implement these technologies. SME Manufacturers in Canada are stretched thinner, and have fewer people assigned to investigate leading edge technologies, than larger operations. Investigating all the available digital technologies available to manufacturing could result in conflicting priorities and may ultimately fail to produce a compelling business case or a clear way forward.

Although widely applicable, the technology cannot be cost-effectively applied to all business operations. Smaller manufacturers need to see implementations of digital twins in companies that are similar

to themselves. Although seeing a power station benefit from an implementation of digital twins may be encouraging to large businesses, a more relevant benefit for manufacturing SMEs is a throughput increase from a single machine resulting in yield improvements of 20%. Use-cases showing common SME equipment and SME applications, will stimulate more technology adoption interest at a smaller shop than learning that a natural gas power plant can save $1B in maintenance costs through the application of the technology.

If the NGen Digital Twin Technology Adoption Advisory Board could present unbiased, data-supported use cases for the adoption of the technology by Canadian SMEs in manufacturing to other SMEs the adoption of the technology would be much higher and more rapid.

Recommendation 2 – Value in a real-world demonstration centre

Multiple survey respondents expressed the attitude of Canadian SME Manufacturers to actually see the benefits of Digital Twins on a realistic shopfloor (or at least in a similar manufacturing environment).

To paraphrase feedback received from survey participants – "Prior to opening my shopfloor for an implementation, I would like to see examples that incorporate equipment that resembles the equipment that is used on my shopfloor. I want to see the actual realized benefits and a representative ROI for the investment. After an example implementation is successfully demonstrated in this environment, I want to understand what the go-forward process would be for me to apply the technology to my floor."

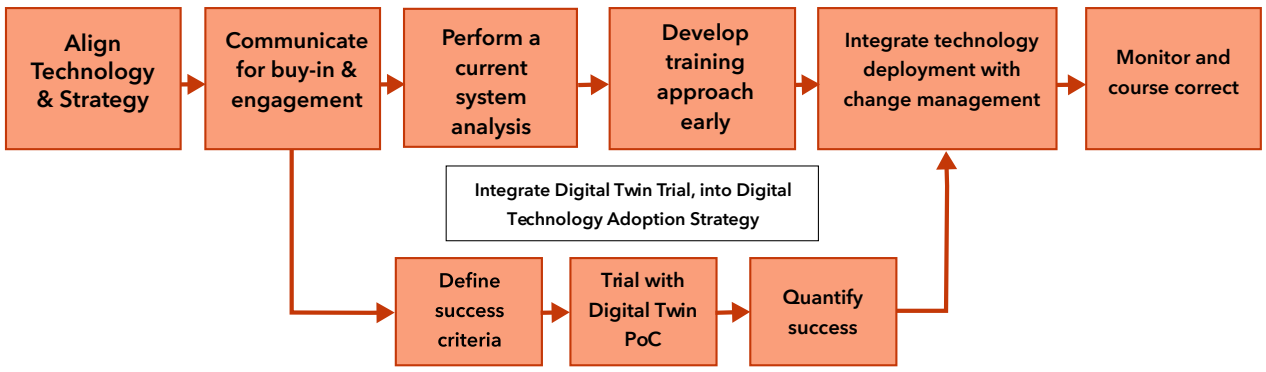
The desire for a real-world implementation with an objective use case and ROI analysis might be accomplished through a demonstration program or in conjunction with a Tech Access Centre and potential collaborations with NRC or NRC/IRAP should be explored.

Recommendation 3 – Canadian SME manufacturers need an implementation roadmap

Scaling the adoption of Digital Twins in manufacturing operations will require roadmaps, compatible standards, workforce strategies and funding strategies.

Integrating a Digital Twin proof-of-concept will be added into the path of a standard technology adoption workflow. Adding a digital twin trial into the adoption roadmap enhances buy-in and engagement across the entire organization. Starting with a single machine (connected to a digital twin), then adding additional machines provides incremental operational improvements, justifying the continued investment.

Many roadmaps exist for digital adoption in a manufacturing plant. How a Digital Twin Trial could enhance a digitization roadmap is presented in the below graphic.



Example - Adoption Roadmap example -7 Steps to Successful Technology Adoption – TLNT

A more detailed and refined roadmap that provides specific guidance and supporting tools to support the implementation of digital twins in manufacturing would be of great potential value. Tools to support ROI projections would also be of great value.

Next Steps – Digital Twin Advisory Board

Working Groups

When (or if) the consensus of the Tech Adoption Advisory Board is such that certain actions are necessary to guide/assist/lead the Canadian Manufacturing sector, and that action is supported within the Community of the Advisory Board, then Working Groups may be formed, held accountable to the Tech Adoption Advisory Board. Early discussions with members of the Technology Adoption Advisory Board have led to the formation of the following Working Groups (reporting to the Advisory Board).

Working Group #1 – Example Implementation (with other implementations to follow)

Objective:

- Provide documentation for public consumption that will enable technology to be adopted by SME Manufacturers in Canada

How:

- Identify an SME with a machine to become twinned – digitally
- Identify a modeling and simulation expert willing to create the physics-based model that simulates the operation of the machine
- Obtain commitments from a professional Project Manager to craft the project plan and produce job specs with time estimates (example tech writer)

What:

- Produce a Digital Twin example implementation operating on the manufacturing floor
- ROI requirements
- Installation and wiring diagrams
- Model and simulation software
- Cost benefit results
- Final white paper use-case for SMEs in Canadian Manufacturing ecosystem

Working Group #2 – Provide awareness of Digital Twin technology to Canadian SME Manufacturers

Objective:

- Provide awareness of Digital Twin technology to Manufacturers
- Provide benefit analysis tool(s) for Canadian SMEs to evaluate their manufacturing processes that determine if their operations can benefit from implementing Digital Twins

How:

- Create a mission statement for the Working Group
- Identify a working group leader with project management skills

- Identify members of the advisory board willing to participate in the working group.
- Identify the internal needs of Advisory Board (members) and ensure any external outreach serves the needs of both (internal/external)

What:

- Provide a plan to improve awareness within the Canadian SME manufacturing ecosystem
- Develop self-assessment benefits analysis tool for adopting Digital Twins technology

Working Group #3 – Digital Twin Curriculum development

Objective:

- Prepare outlines for Digital Twin Courses, that can be used as guidance to create courses that will produce Digital Twin graduates in Canada

How:

- Utilize skills of the technology community to develop training programming with a strong focus on the needs of industry and the application of digital twinning to solve industrial problems with strong ROI

What:

- Produce course outlines that identifies the topics and training modules necessary to prepare graduates to enter the workforce, ready to implement digital twin technologies in Canadian Manufacturers

Digital Twin Cluster

A Digital Twin Cluster could be formed by interested members of the NGen Digital Twin Advisory Board. Working Group activities could be expanded upon and transferred to the Digital Twin Cluster. Application for funding for a maximum from NGen is $75K (when matched with industry $75K). Interested members from the Advisory Board would need to be identified to carry this forward. The Digital Twin Cluster could be chartered to bring awareness of the technology benefits, to the Canadian Manufacturing ecosystem.

Conclusion

Digital Twin technology is early in the adoption cycle for Canadian SME Manufacturing. Many larger companies have adopted the technology and benefited from integrating model-based simulations into the monitoring and control loops of manufacturing processes. As well, many manufacturers have benefited from the digitization of the manufacturing workflow. Adopting Digital Twins by Canadian SMEs has enormous potential for improving costs, cycle-times, and quality levels. This report has captured the feedback from multiple service providers/SMEs and identifies a gradual adoption method for Digital Twins. With gradual adoption of the technology, businesses will prove the value of Digital Twins on the manufacturing floor, and roll-out additional Digital Twin implementations aligned with an overall digital strategy.

Authors of Report

Contributors to the Report

Mathieu Goulet of CRVI Robotique Vision
Thomas Tartiere of Panevo Services Limited
Hobivola A. Rabearivelo of BI Expertise
David McNally of Agyle Intelligence
Rajiv Anand of Quartic.ai Canada, Inc.
Ken Morris of NGen (Next Generation Manufacturing Canada)

Editors of the Report

Khizer Hayat of IFIVEO Canada Inc.
Mark Kirby of the Multi-Scale Additive Manufacturing Lab at University of Waterloo
Stewart Cramer of NGen (Next Generation Manufacturing Canada)
Ken Morris of NGen (Next Generation Manufacturing Canada)

References

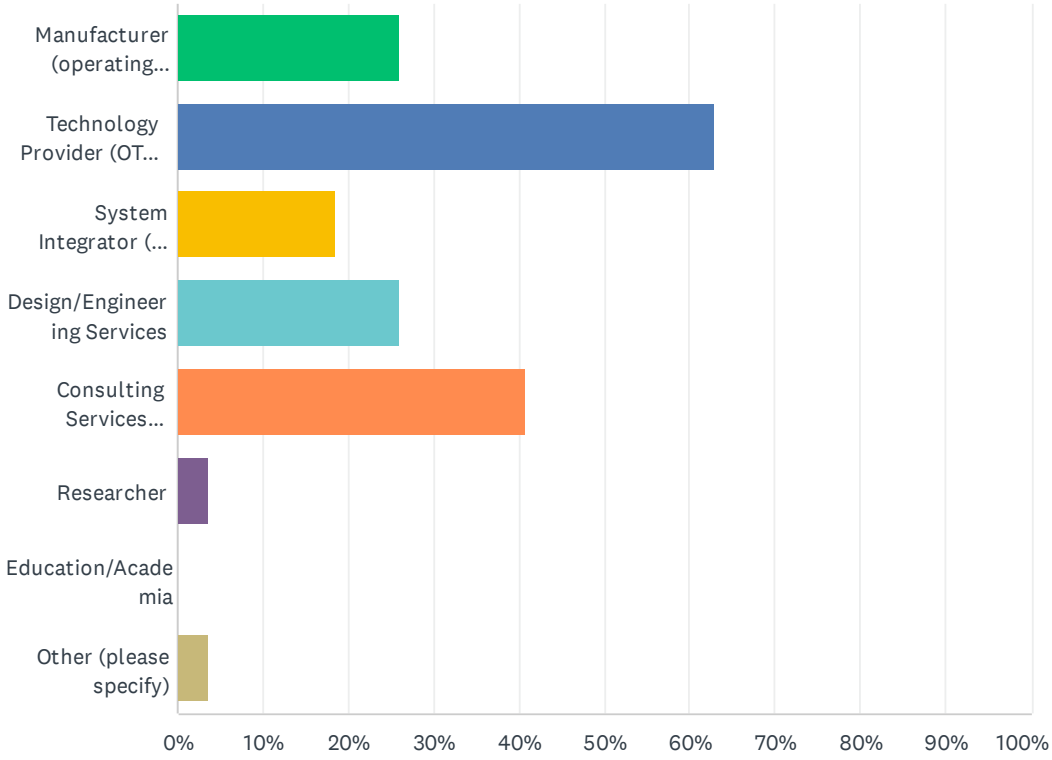
1. Kritzinger, W., Karner, M., T. G., H. J., & Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. IFAC PapersOnLine 51-11 (2018) (pp. 1016-1022). International Federation of Automatic Control (IFAC).

2. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems - Dr. Michael Grieves and John Vickers, August 2016

Appendix A

Q1 What best describes your main business? (Check all that apply)

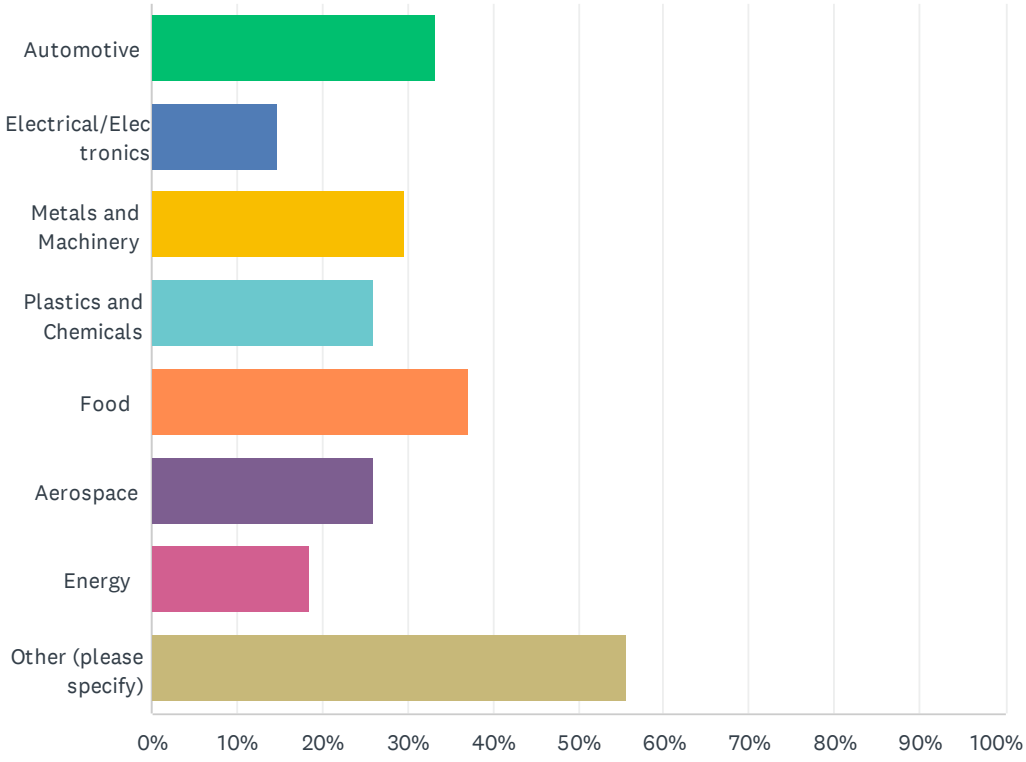
Answered: 27 Skipped: 0



ANSWER CHOICES	RESPONSES	
Manufacturer (operating factories, assembling products)	25.93%	7
Technology Provider (OT and/or IT, hardware, software, and/or services)	62.96%	17
System Integrator (OT and/or IT)	18.52%	5
Design/Engineering Services	25.93%	7
Consulting Services (Business/Management and/or Tech)	40.74%	11
Researcher	3.70%	1
Education/Academia	0.00%	0
Other (please specify)	3.70%	1
Total Respondents: 27		

Q2 What are your main customer/client market(s)?

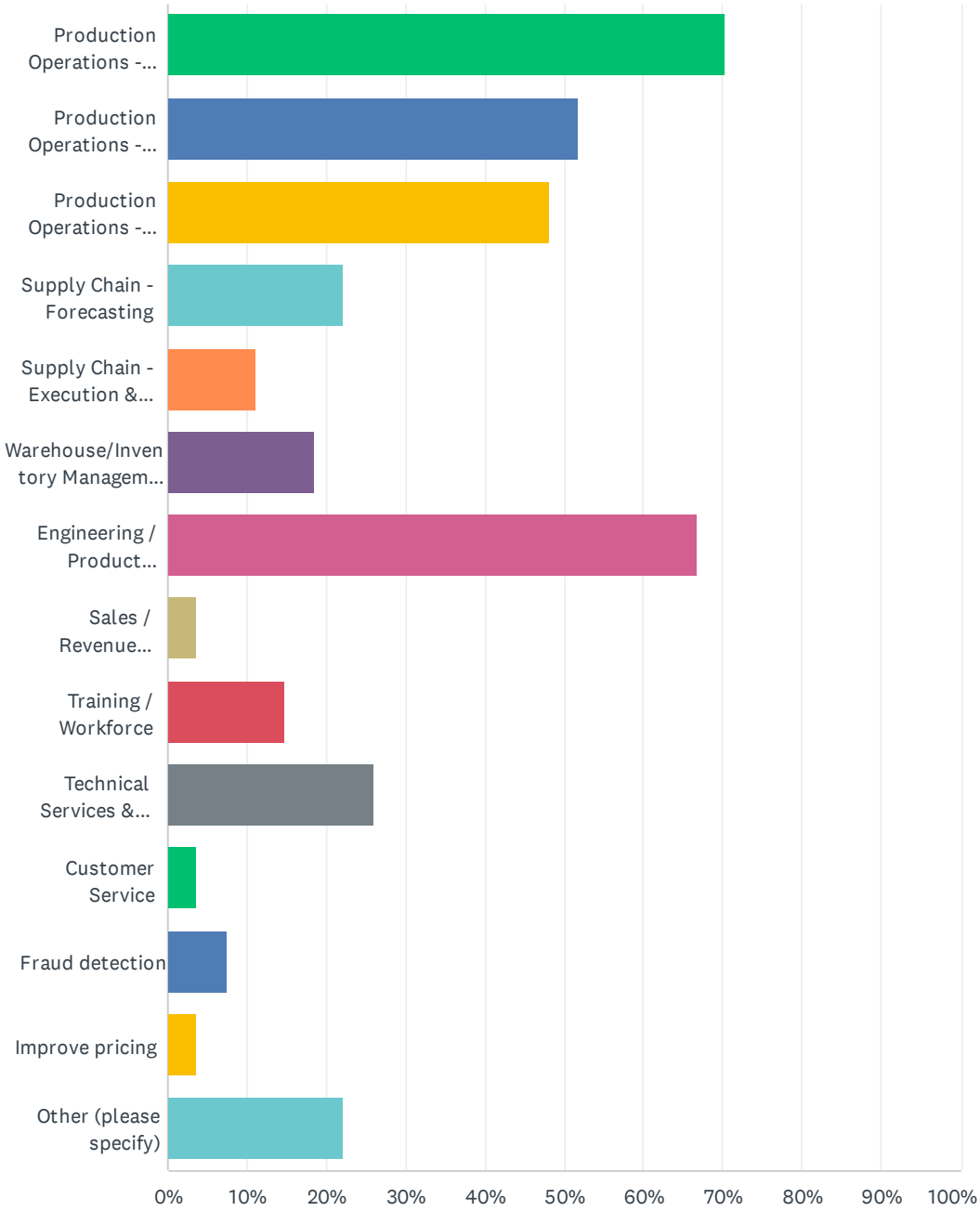
Answered: 27 Skipped: 0



ANSWER CHOICES	RESPONSES	
Automotive	33.33%	9
Electrical/Electronics	14.81%	4
Metals and Machinery	29.63%	8
Plastics and Chemicals	25.93%	7
Food	37.04%	10
Aerospace	25.93%	7
Energy	18.52%	5
Other (please specify)	55.56%	15
Total Respondents: 27		

Q3 What are the main application areas for your product/services? (Check all that apply)

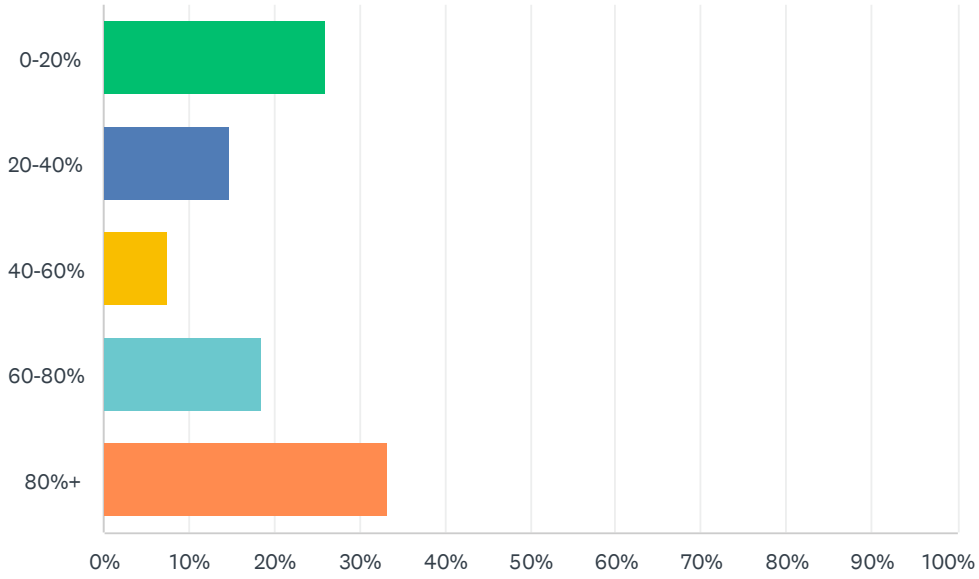
Answered: 27 Skipped: 0



ANSWER CHOICES	RESPONSES	
Production Operations - Improve Uptime / OEE / Output	70.37%	19
Production Operations - Find Cost Savings	51.85%	14
Production Operations - Quality Improvement / Zero Defects / Root Cause	48.15%	13
Supply Chain - Forecasting	22.22%	6
Supply Chain - Execution & Transportation Management	11.11%	3
Warehouse/Inventory Management & Internal Logistics	18.52%	5
Engineering / Product Development	66.67%	18
Sales / Revenue Growth/Biz Dev	3.70%	1
Training / Workforce	14.81%	4
Technical Services & Maintenance	25.93%	7
Customer Service	3.70%	1
Fraud detection	7.41%	2
Improve pricing	3.70%	1
Other (please specify)	22.22%	6
Total Respondents: 27		

Q4 Roughly what percentage of your business (sales) is to Canadian businesses?

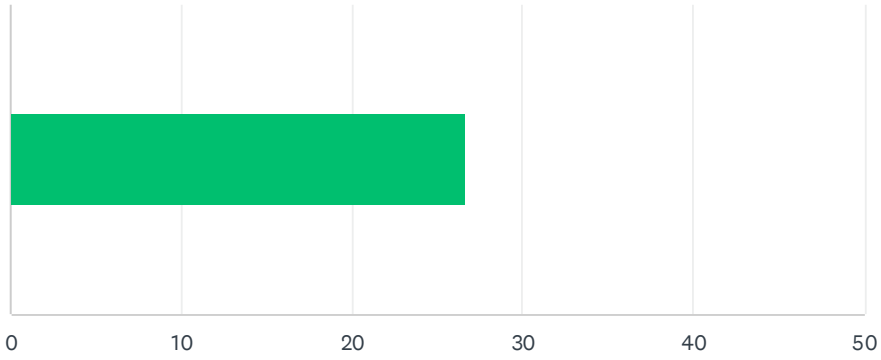
Answered: 27 Skipped: 0



ANSWER CHOICES	RESPONSES	
0-20%	25.93%	7
20-40%	14.81%	4
40-60%	7.41%	2
60-80%	18.52%	5
80%+	33.33%	9
TOTAL		27

Q5 Do you think Canadian companies are well informed about the business case for Digital Twins? (Please drag the slider)

Answered: 27 Skipped: 0



ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	27	720	27
Total Respondents: 27			

Q6 How could awareness about Digital Twins be improved in Canada?

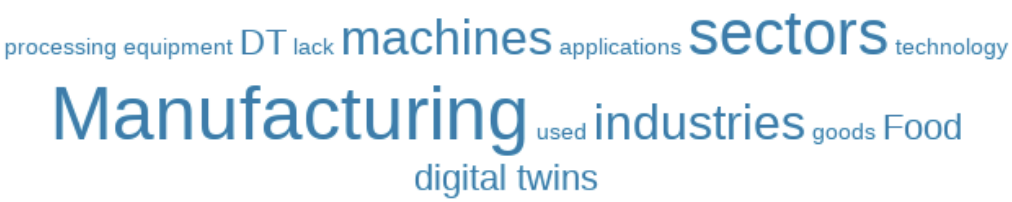
Answered: 26 Skipped: 1

Q7 In your opinion describe the best use case of Digital Twins deployed (or planned) in Canada?

Answered: 25 Skipped: 2

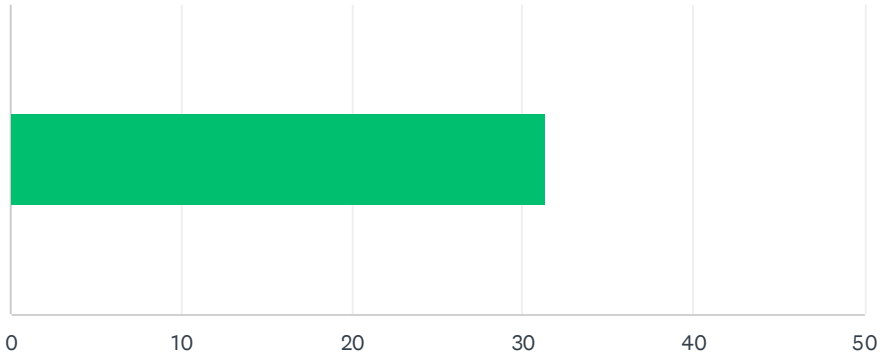
Q8 What market sectors and/or applications do you think are under exploited in Canada for Digital Twins?

Answered: 26 Skipped: 1



Q9 Canada is adequately preparing students and workers for the future of Digital Twins.

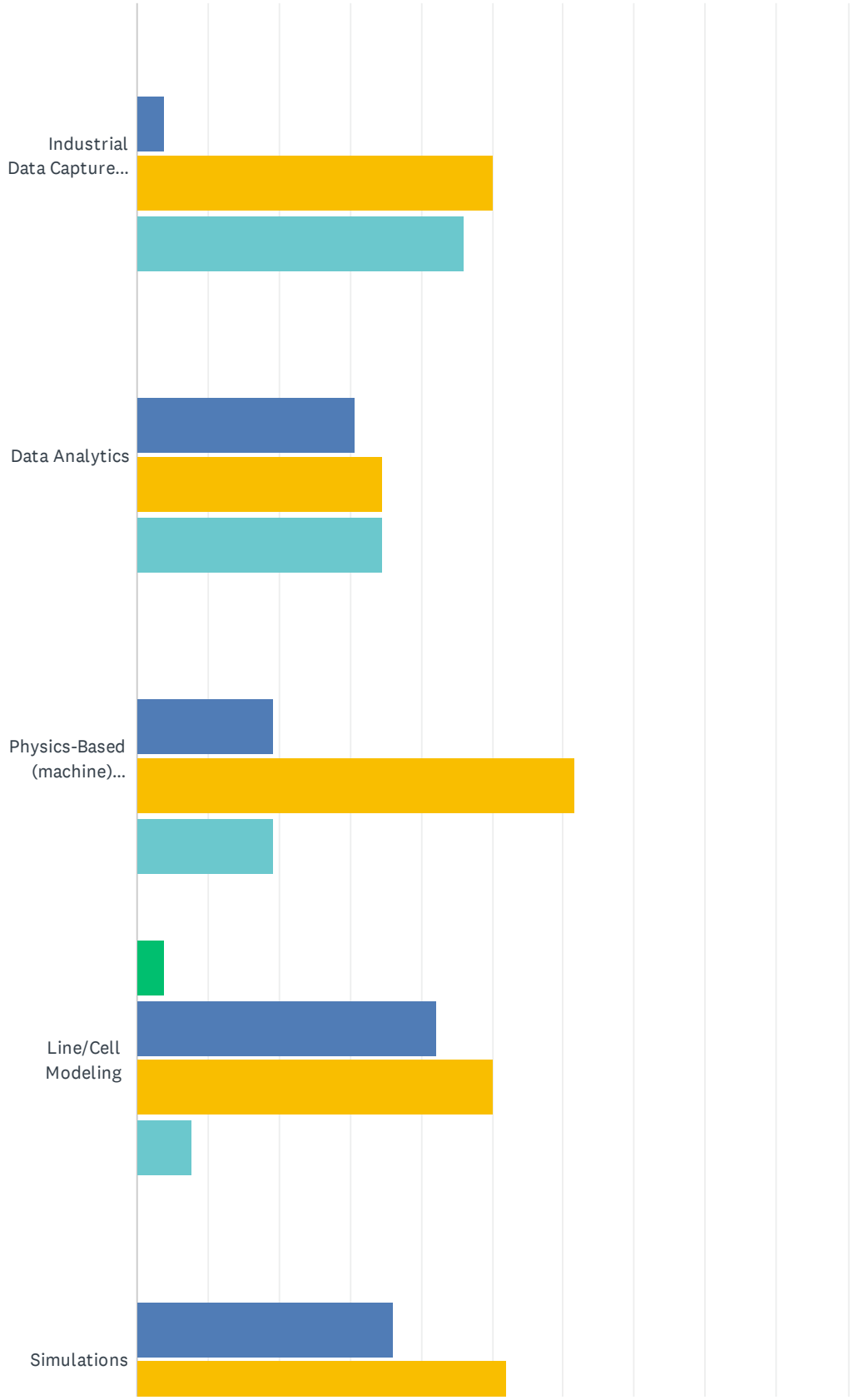
Answered: 20 Skipped: 7

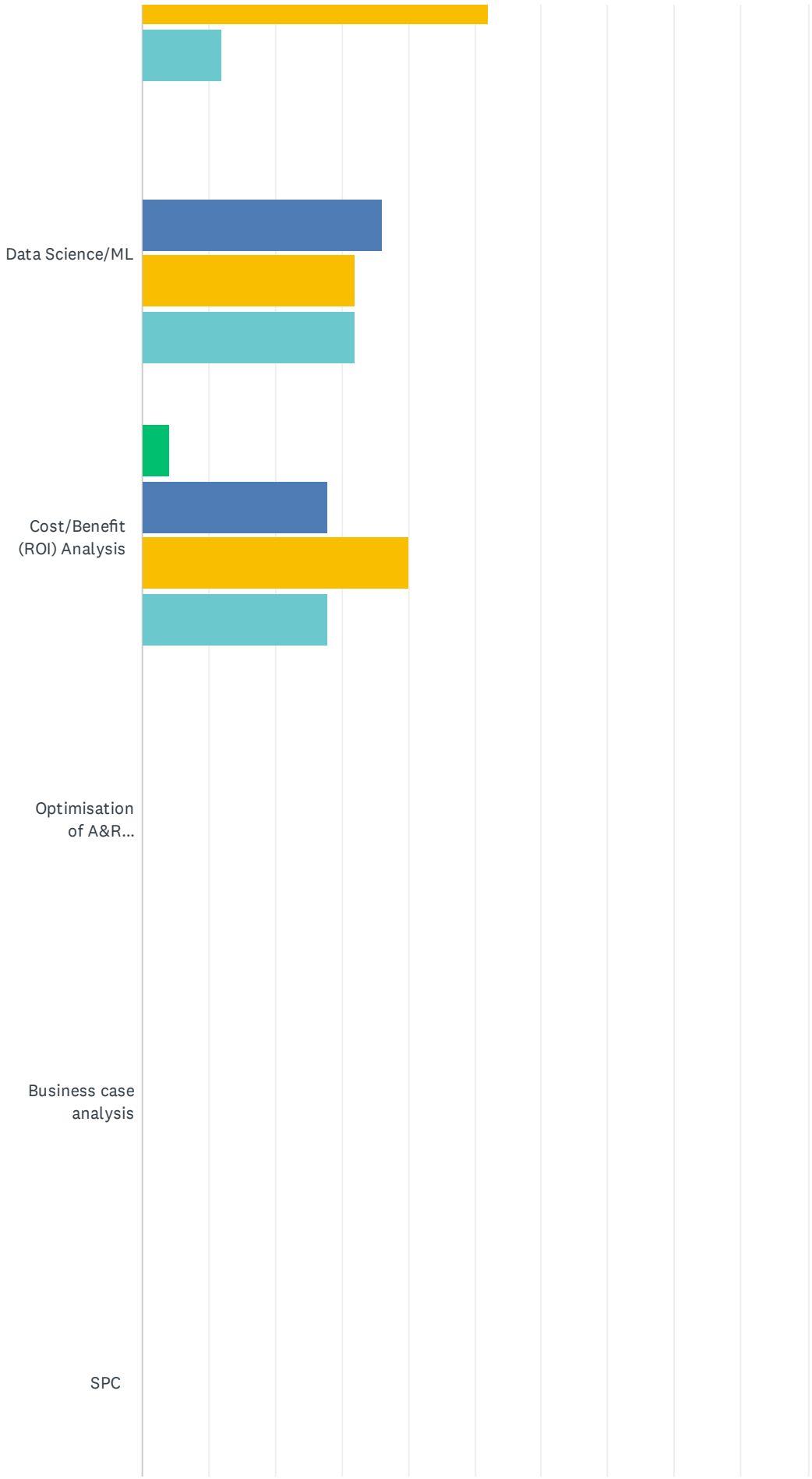


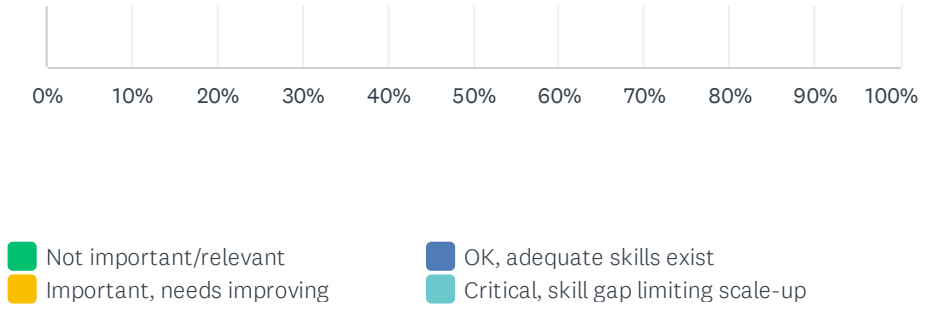
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	31	626	20
Total Respondents: 20			

Q10 What skill sets are most important for SMEs to adopt Digital Twins?

Answered: 26 Skipped: 1



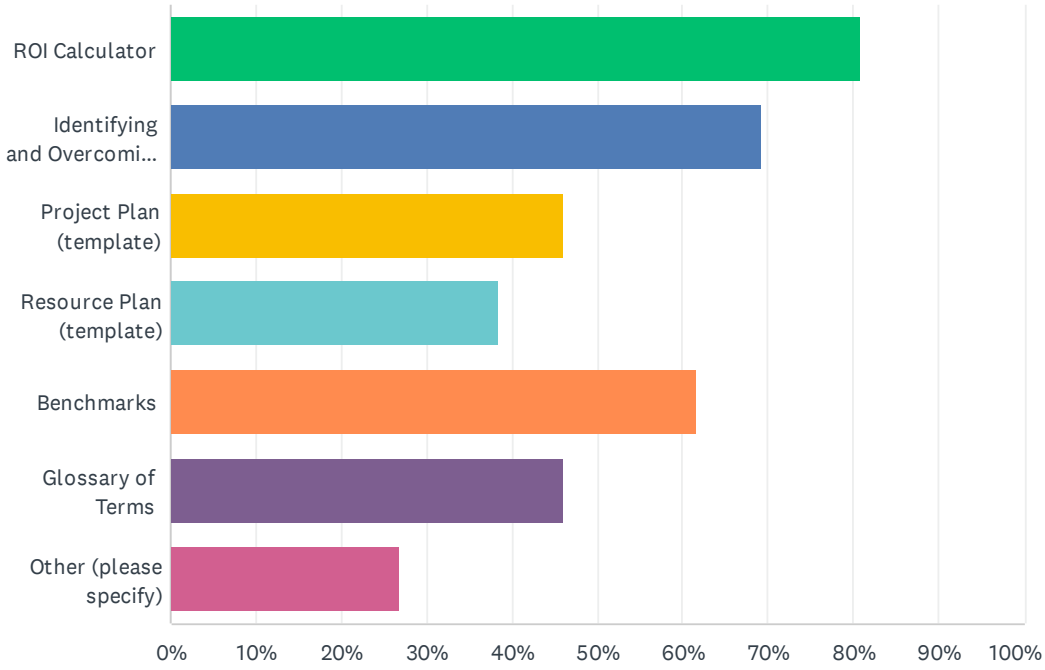

Data Science/ML
Cost/Benefit (ROI) Analysis
Optimisation of A&R...
Business case analysis
SPC



	NOT IMPORTANT/RELEVANT	OK, ADEQUATE SKILLS EXIST	IMPORTANT, NEEDS IMPROVING	CRITICAL, SKILL GAP LIMITING SCALE-UP	TOTAL RESPONDENTS
Industrial Data Capture / IoT	0.00% 0	3.85% 1	50.00% 13	46.15% 12	26
Data Analytics	0.00% 0	30.77% 8	34.62% 9	34.62% 9	26
Physics-Based (machine) Modeling	0.00% 0	19.23% 5	61.54% 16	19.23% 5	26
Line/Cell Modeling	3.85% 1	42.31% 11	50.00% 13	7.69% 2	26
Simulations	0.00% 0	36.00% 9	52.00% 13	12.00% 3	25
Data Science/ML	0.00% 0	36.00% 9	32.00% 8	32.00% 8	25
Cost/Benefit (ROI) Analysis	4.00% 1	28.00% 7	40.00% 10	28.00% 7	25
Optimisation of A&R processes	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0
Business case analysis	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0
SPC	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0

Q11 What project documents and technical documents are needed by Manufacturing SMEs in Canada for adopting Digital Twins?

Answered: 26 Skipped: 1



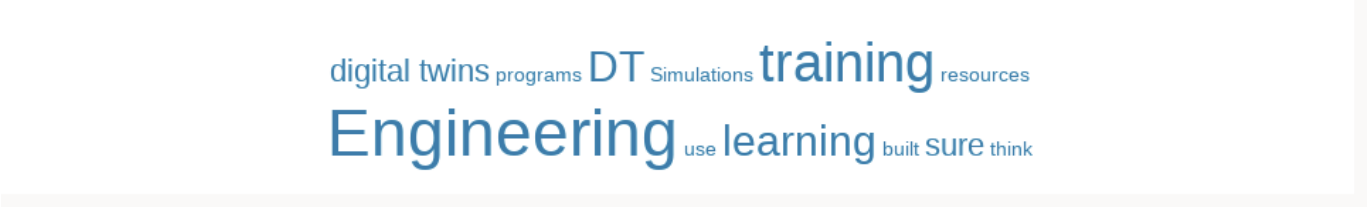
ANSWER CHOICES	RESPONSES	
ROI Calculator	80.77%	21
Identifying and Overcoming Roadblocks	69.23%	18
Project Plan (template)	46.15%	12
Resource Plan (template)	38.46%	10
Benchmarks	61.54%	16
Glossary of Terms	46.15%	12
Other (please specify)	26.92%	7
Total Respondents: 26		

Q12 What existing investments of digitization can be leveraged, by Canadian SMEs for Digital Twin integration? (Existing investments of digitization could include simulations, models, VR/AR training, process management, supply chain management, and other digital assets)

Answered: 25 Skipped: 2

Q13 What do you think is the best example of Digital Twin skills training in Canada?

Answered: 25 Skipped: 2

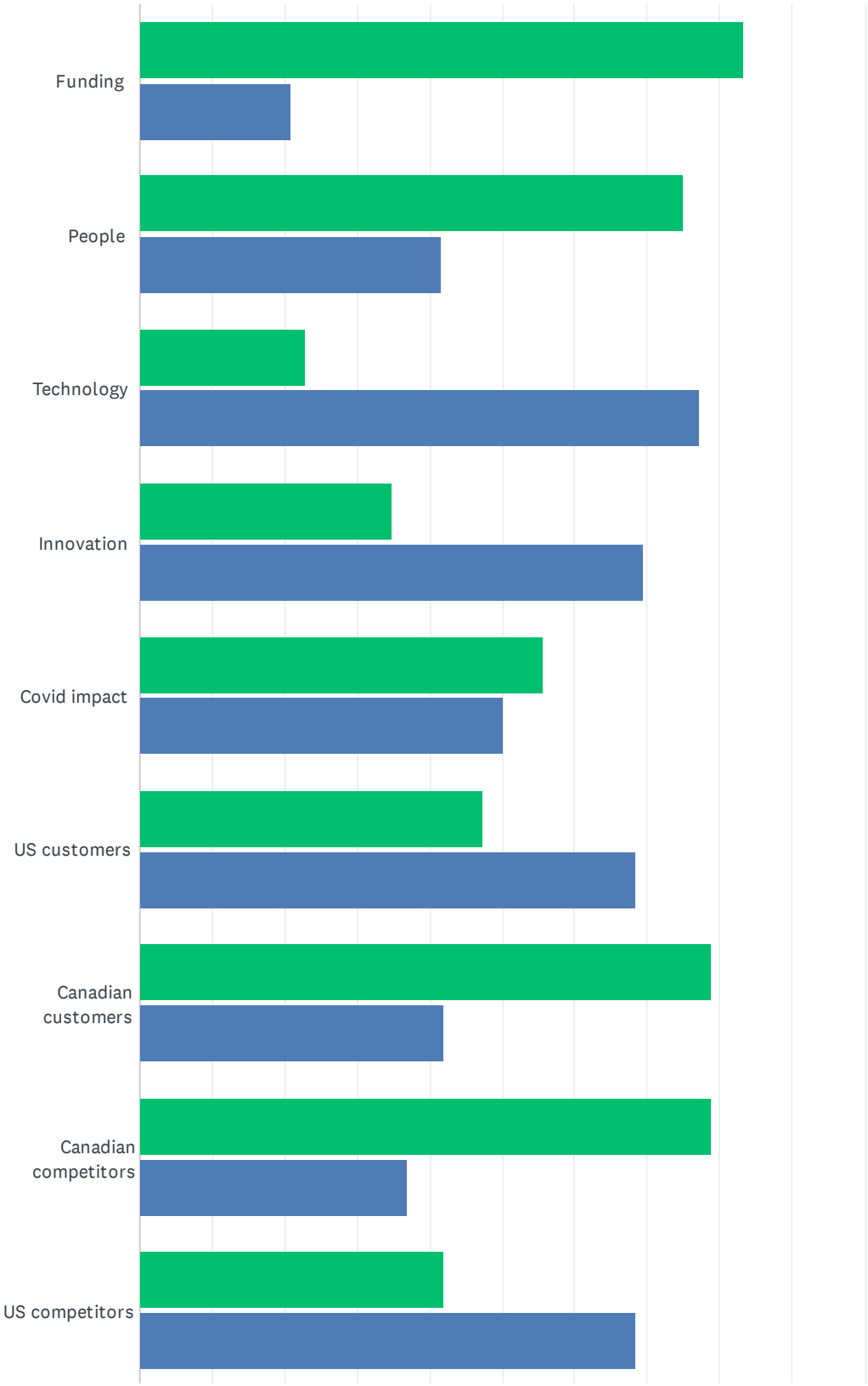


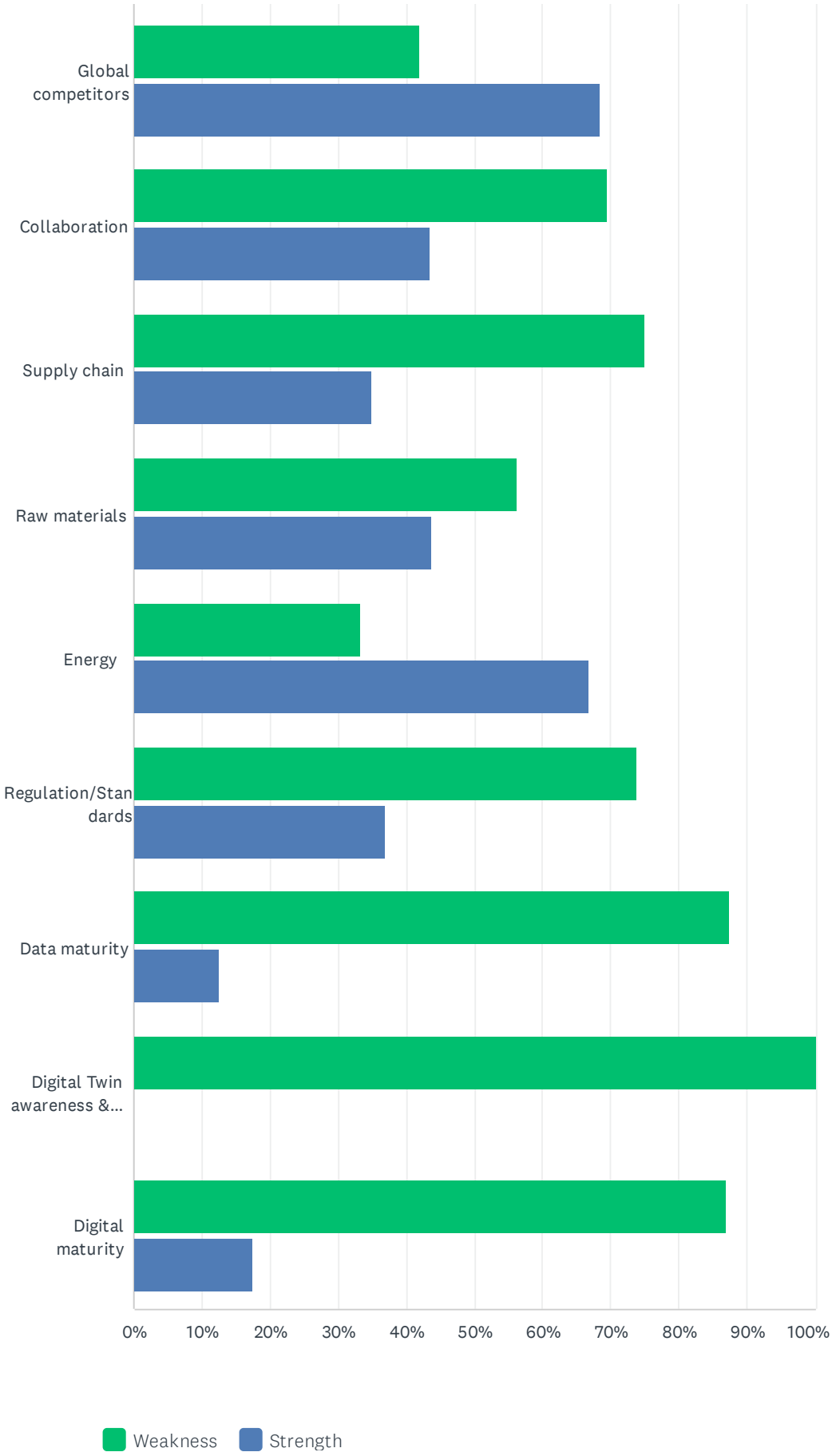
Q14 Can NGen help improve Digital Twin skills, if so how?

Answered: 26 Skipped: 1

Q15 Please give your opinion on issues affecting Digital Twin adoption in Canada (Note: An issue/area could be both a weakness and a strength)

Answered: 25 Skipped: 2




Global competitors
Collaboration
Supply chain
Raw materials
Energy
Regulation/Standards
Data maturity
Digital Twin awareness &...
Digital maturity
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Weakness
Strength

	WEAKNESS	STRENGTH	TOTAL RESPONDENTS
Funding	83.33% 20	20.83% 5	24
People	75.00% 18	41.67% 10	24
Technology	22.73% 5	77.27% 17	22
Innovation	34.78% 8	69.57% 16	23
Covid impact	55.56% 10	50.00% 9	18
US customers	47.37% 9	68.42% 13	19
Canadian customers	78.95% 15	42.11% 8	19
Canadian competitors	78.95% 15	36.84% 7	19
US competitors	42.11% 8	68.42% 13	19
Global competitors	42.11% 8	68.42% 13	19
Collaboration	69.57% 16	43.48% 10	23
Supply chain	75.00% 15	35.00% 7	20
Raw materials	56.25% 9	43.75% 7	16
Energy	33.33% 6	66.67% 12	18
Regulation/Standards	73.68% 14	36.84% 7	19
Data maturity	87.50% 21	12.50% 3	24
Digital Twin awareness & comprehension	100.00% 25	0.00% 0	25
Digital maturity	86.96% 20	17.39% 4	23

Q16 What are the structural advantages (in your opinion) that Canada has for Digital Twins?

Answered: 25 Skipped: 2

Q17 What in are the structural weaknesses (in your opinion) that Canada faces in Digital Twins?

Answered: 25 Skipped: 2

Q18 What actions will improve the adoption of Digital Twins in Canada?

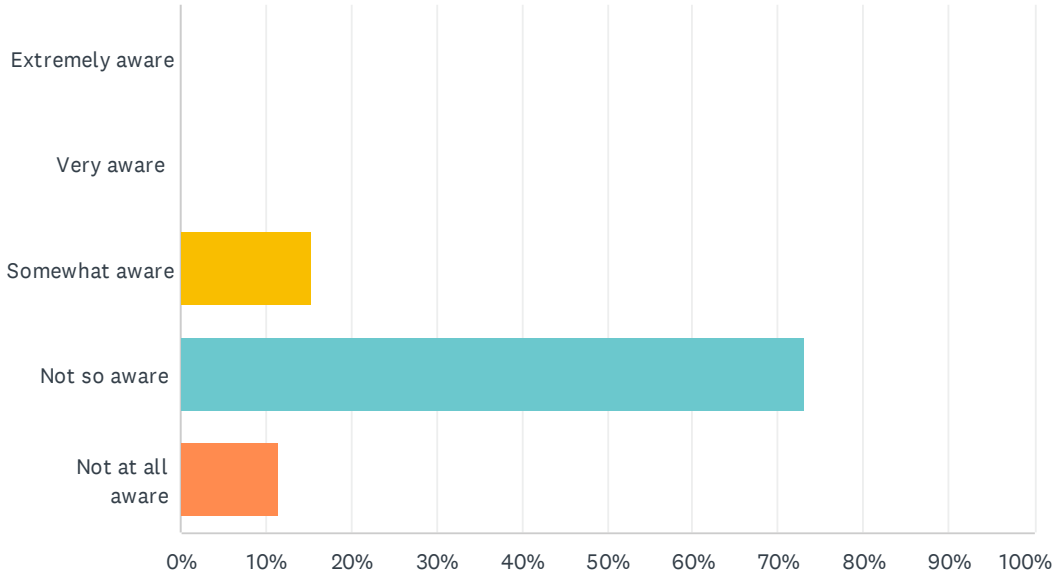
Answered: 26 Skipped: 1

Q19 What question(s) would you like to ask NGen's membership about Digital Twins?

Answered: 23 Skipped: 4

Q20 Do you think Canadian businesses are aware of how they can benefit from Digital Twins?

Answered: 26 Skipped: 1



ANSWER CHOICES	RESPONSES	
Extremely aware	0.00%	0
Very aware	0.00%	0
Somewhat aware	15.38%	4
Not so aware	73.08%	19
Not at all aware	11.54%	3
TOTAL		26

Q21 Please describe the knowledge level of your typical customer as it relates to your product or service.

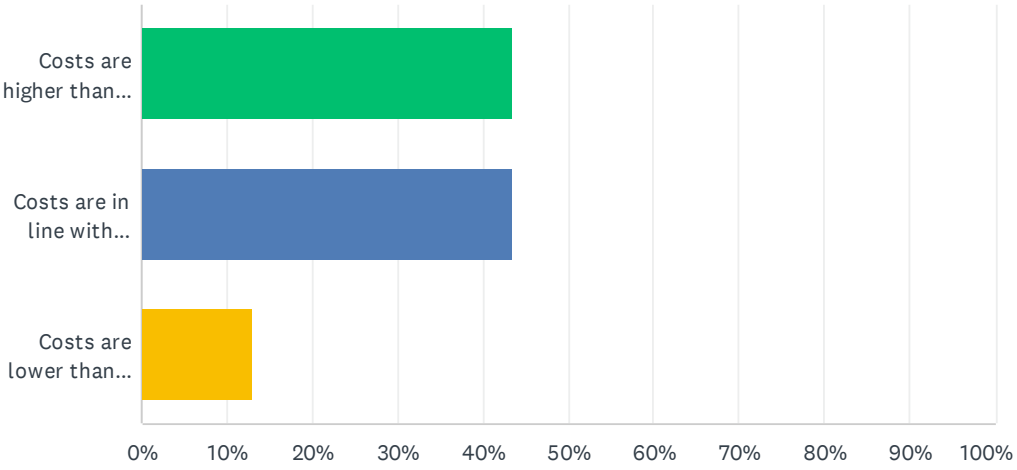
Answered: 26 Skipped: 1

Q22 Please describe the typical expectation that your clients have regarding your offering (technology/product/service/solution). Do your clients envision your offering capabilities appropriately, or do your clients expect your offering to be less (or more) capable than the offering really is?

Answered: 25 Skipped: 2

Q23 Do your customers have a sense of the costs associated with your product or service?

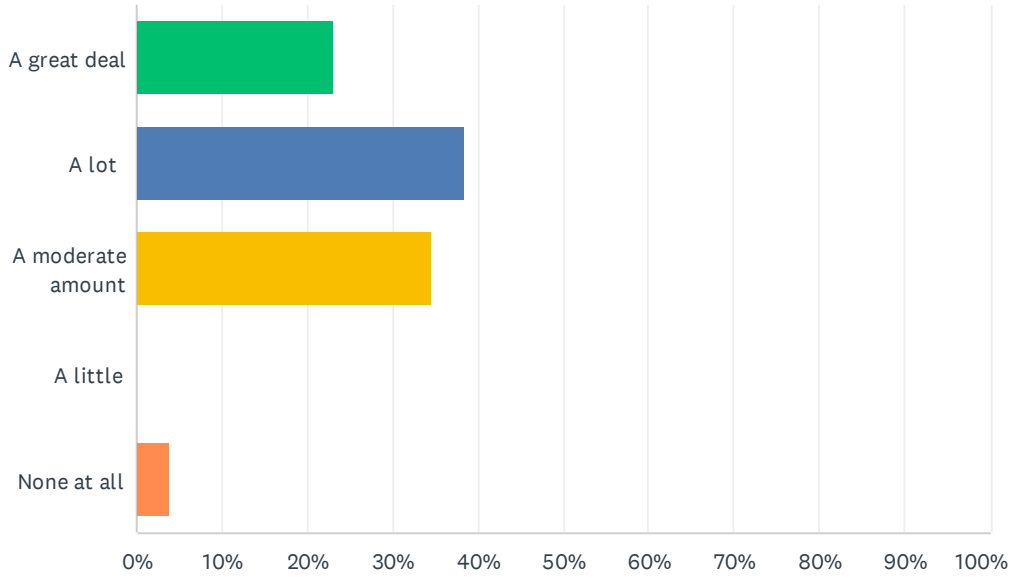
Answered: 23 Skipped: 4



ANSWER CHOICES	RESPONSES	
Costs are higher than expected	43.48%	10
Costs are in line with expectations	43.48%	10
Costs are lower than expected	13.04%	3
TOTAL		23

Q24 How much of your time and effort is spent educating the customer on the technology/product/service, and it's benefits?

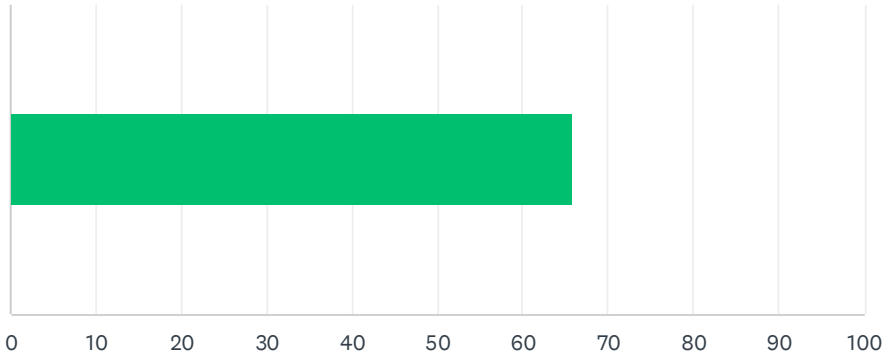
Answered: 26 Skipped: 1



ANSWER CHOICES	RESPONSES	
A great deal	23.08%	6
A lot	38.46%	10
A moderate amount	34.62%	9
A little	0.00%	0
None at all	3.85%	1
TOTAL		26

Q25 How likely are you to participate in a Digital Twins Workshop, with the Standards Council of Canada as a DT Manufacturing representative?

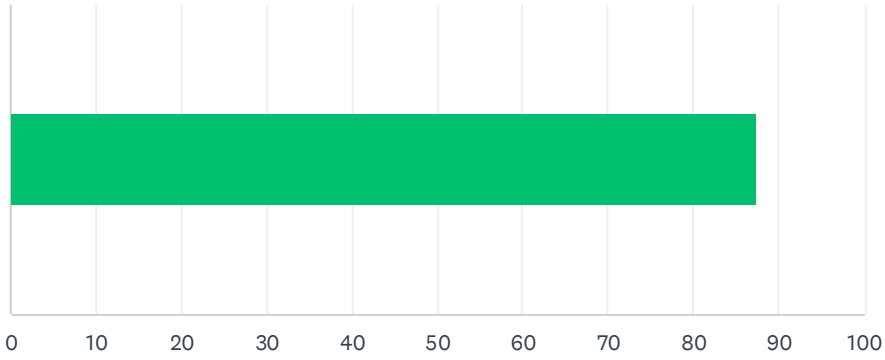
Answered: 25 Skipped: 2



ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	66	1,646	25
Total Respondents: 25			

Q26 Would an example project of a Digital Twin implementation be useful or valuable for Canadian SME Manufacturers?

Answered: 26 Skipped: 1



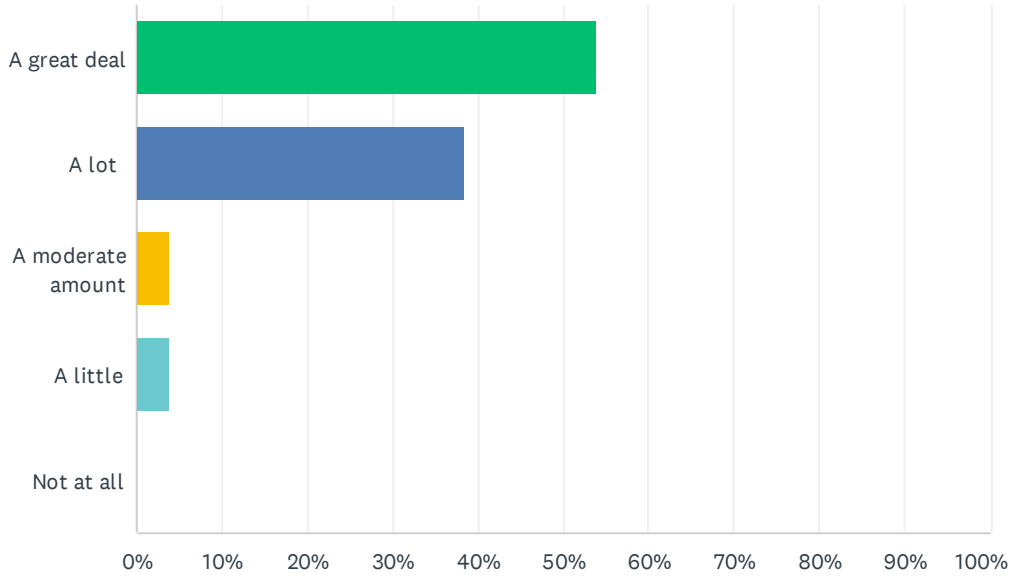
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	87	2,273	26
Total Respondents: 26			

Q27 What demonstration facilities/resources are you aware of for Digital Twins in Canada?

Answered: 25 Skipped: 2

Q28 Would more demonstration facilities/resources help industry adoption of Digital Twins?

Answered: 26 Skipped: 1



ANSWER CHOICES	RESPONSES	
A great deal	53.85%	14
A lot	38.46%	10
A moderate amount	3.85%	1
A little	3.85%	1
Not at all	0.00%	0
TOTAL		26

Q29 Should a new demo facility be physical or virtual, and showcasing what?

Answered: 26 Skipped: 1