

Post COVID-19: Application of Data Visualization Technology at Manufacturing Sector in Malaysia

MN Azhar*, AIM Shaiful and MN Omar

Faculty of Mechanical Engineering and Technology, Universiti Malaysia Perlis, Kampus Pauh Putra, 02600 Arau, Perlis, Malaysia

***Corresponding Author:** MN Azhar, Faculty of Mechanical Engineering and Technology, Universiti Malaysia Perlis, Kampus Pauh Putra, 02600 Arau, Perlis, Malaysia.

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Abstract

The COVID-19 pandemic has had a significant impact on the manufacturing sector including Malaysia, causing supply chain disruptions, decreased demand, and production shutdowns. This has resulted in a decrease in output and disruptions to global trade, with some sectors rebounding while others continue to struggle. Industry 4.0 technologies, such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, and real-time data visualization dashboard can assist manufacturers in overcoming these challenges by increasing flexibility, efficiency, and resilience in their operations. Real-time data visualization dashboard tools, a technology from Industry 4.0, can provide operational insights into manufacturing processes, and help identify areas for improvement. These platform can also assist in remote monitoring, management, and predictive analysis, which can help manufacturers mitigate the effects of the pandemic and become more resilient in the face of future disruptions. This research studies among Malaysia's manufacturers have found that the majority agree that Industry 4.0 is more valuable during and at post-pandemic, with real-time data visualization tools being the most important elements for tackling the top issues such as inventory management and process yield improvement. However, many manufacturers are still in the pilot run, and there are challenges to be faced in the post-COVID-19 recovery phase, including managing organizational mindset, culture, and customer needs.

Keywords: COVID-19; Industry 4.0; Industry4WRD; Manufacturing; Data Visualization; Dashboard

Introduction

COVID-19 pandemic impact to the manufacturing sector

The COVID-19 pandemic has profoundly affected the manufacturing sector, leading to supply chain disruptions, decreased demand, and government-mandated shutdowns. These factors coalesced to diminish production and disrupt global trade, with many companies grappling with the challenges of remote work and enforcing social distancing protocols in the factories [1]. As the world enters the post-pandemic phase, the manufacturing sector presents a mixed picture. While some sectors have experienced a resurgence in demand and production, others remain beleaguered by persistent supply chain disruptions and future uncertainties. The net outcome is a tangible reduction in manufacturing output and a continued disturbance to global trade. The impact of the pandemic on Malaysia's manufacturing sector has been significant. Data from the Department of Statistics Malaysia reveals that the manufacturing sales index plummeted by 9.7 percent in April 2020 compared to the same month in the previous year, attesting to the disruption precipitated by the pandemic [2]. Concurrently, exports of manufactured goods - which constitute the majority of Malaysia's exports - suffered a 17.1 percent contraction in April 2020 compared to the same month in the preceding year. The Electronics and Electrical (E&E) sector, a

linchpin of Malaysia's manufacturing industry, has not been immune to the effects of the pandemic. The Semiconductor Industry Association reported an 8.6 percent decline in global semiconductor sales in 2020, aligning with a 12.4 percent contraction in Malaysia's E&E exports in the second quarter of 2020 compared to the corresponding period in the previous year. In response to the pandemic's deleterious impact on the manufacturing sector, the Malaysian government has introduced a raft of measures. These include providing financial aid to affected businesses and implementing strategies to facilitate the resumption of operations within the sector. Despite these interventions, the timeline for a full recovery of Malaysia's manufacturing sector remains uncertain.

Industry 4.0 adoption assist struggle manufacturer during COVID-19 pandemic

Industry 4.0 technologies, such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, real-time data visualization, and advanced automation, can help manufacturers ease the impact of the COVID-19 pandemic by allowing for greater flexibility, efficiency, and resilience in their operations [3].

- a) Flexibility: Industry 4.0 technologies can allow manufacturers to quickly adjust production processes and respond to changes in demand, which is particularly important during times of uncertainty such as the COVID-19 pandemic.
- b) Efficiency: Industry 4.0 technologies can increase the efficiency of manufacturing operations, reducing the need for human labor and enabling companies to maintain production levels even with reduced workforce.
- c) Resilience: Industry 4.0 technologies, such as predictive maintenance and real-time monitoring, can help companies detect and respond to potential disruptions in their supply chains.
- d) Remote Monitoring and Management: Industry 4.0 technologies such as remote monitoring, control and management can help companies to monitor and control the production remotely, which can be helpful during times when on-site presence is not possible due to pandemics or other reasons.
- e) Predictive Analysis: Industry 4.0 technologies such as Predictive analysis can help companies to identify and anticipate future disruptions, allowing them to prepare and respond more effectively.

Overall, Industry 4.0 technologies can help manufacturers to mitigate the effects of the COVID-19 pandemic and become more resilient in the face of future disruptions. Below are some general facts and figures that have been reported in past studies and surveys [4]:

- A survey conducted by PwC in 2020 found that 67 percent of manufacturers reported that the pandemic had accelerated their plans to adopt Industry 4.0 technologies.
- A survey conducted by Deloitte in 2020 found that 70 percent of manufacturing companies were investing in Industry 4.0 technologies to improve their operations and increase efficiency in response to the pandemic.
- A survey conducted by McKinsey in 2020 found that 85 percent of companies had accelerated their digital transformation plans as a result of the pandemic.
- Another survey conducted by McKinsey in 2020 found that 70 percent of companies had accelerated the deployment of automation and robotization in response to the pandemic.
- A survey conducted by the World Economic Forum in 2020 found that 60 percent of companies were investing in Industry 4.0 technologies to improve their supply chain resilience in response to the pandemic.

Data Visualization among the key Industry 4.0 technology enabler for manufacturing sector

Data visualization tools represent a critical component for successful Industry 4.0 adoption within the manufacturing sector, primarily due to their capacity to facilitate the interpretation and analysis of voluminous data sets [5, 6]. Industry 4.0, also referred to as the fourth industrial revolution, is typified by the incorporation of sophisticated technologies such as the Internet of Things (IoT), artificial intelligence (AI), and automation into manufacturing processes. These technological integrations inevitably generate an extensive amount of data, the analysis of which can prove challenging without the assistance of data visualization tools. Data visualization tools provide a powerful means for manufacturers to discern patterns, trends, and insights within their data. The elucidation of these elements can subsequently inform process optimization, efficiency enhancement, and data-driven decision making. Additionally,

these tools can serve a crucial role in real-time monitoring and performance tracking of interconnected devices and equipment. This can expedite the identification and troubleshooting of potential issues, thereby reducing downtime and mitigating operational disruptions. In summary, data visualization constitutes an indispensable tool for the manufacturing sector as it navigates the transition to Industry 4.0. The ability to effectively visualize and interpret complex data sets not only unlocks the full potential of Industry 4.0, but also positions manufacturers to maintain competitiveness within an increasingly digital industrial landscape.

Data visualization is a technique that graphically represents data, utilizing formats such as charts, graphs, or maps. This method is particularly effective in interpreting large and complex data sets, enabling rapid identification of patterns, trends, and anomalies [7]. This discussion aims to elaborate on the significance of data visualization, explore various visualization types, and propose best practices for creating efficacious visualizations. The paramount importance of data visualization is magnified in the context of the current data landscape, where the volume of data being generated and collected is burgeoning. As this expansion progresses, the ability to comprehend such vast quantities of data becomes increasingly challenging. Data visualization offers a solution to this predicament, transforming otherwise dense and potentially inaccessible data into a more consumable and understandable format. This transformation facilitates swift pattern recognition and trend identification, which may remain concealed within the complexity of raw data.

Data visualization tools not only facilitate the interpretation of complex datasets but also aid in communicating data-driven insights to others, thereby streamlining the decision-making process that relies heavily on data [8]. A multitude of data visualization types exist, each possessing unique strengths and potential limitations. Common types encompass bar charts, line charts, scatter plots, and heat maps. Bar charts are particularly effective for comparing categorical data, whereas line charts are adept at tracing changes over time. Scatter plots excel in unveiling patterns and relationships within data, and heat maps adeptly illustrate areas of high and low density. When crafting a data visualization, one crucial consideration is the selection of the appropriate visualization type that best aligns with the nature of the data and the insights sought. The choice of visualization is fundamentally contingent on the type of data at hand and the intended narrative or message. For instance, utilizing a bar chart to represent time-series data would be suboptimal, whereas a line chart would be a more fitting choice.

An essential factor in data visualization is clarity, ensuring that the graphical representation is easily interpretable. This involves the appropriate use of scales, axes, and labels, along with the selection of distinguishable colors and design elements [8]. Moreover, it is crucial to ensure the accuracy of the visualization, which necessitates the correct representation of the data. This can be accomplished through meticulous data cleaning and transformation techniques, and by verifying the visualization against the original data set. The creation of efficacious data visualizations also requires adherence to best practices in design. A fundamental principle is to maintain simplicity and avoid clutter in the visualizations. This can be achieved by eliminating extraneous elements and emphasizing the most salient information. Another key principle involves the strategic use of colors and other design elements to enhance the aesthetic appeal of the visualizations, making them more engaging and easier to comprehend.

Application of Data Visualization platform in manufacturing sectors

It is challenging to definitively identify the most prevalent data visualization tool within manufacturing applications due to variations across different companies and industries [9]. Nevertheless, Tableau and Microsoft Power BI are frequently cited as among the most widely employed tools within the manufacturing sector. Tableau's popularity stems from its intuitive interface and drag-and-drop functionality, enabling users to effortlessly create interactive dashboards and visualizations [10]. Furthermore, it supports a broad spectrum of data connectors and accommodates various data sources. Conversely, Microsoft Power BI, an integral part of the Microsoft Office Suite, is another favored choice among manufacturers. Its popularity can be attributed to its seamless integration capabilities with other Microsoft products, such as Excel, as well as its robust data modeling and exploration features [11, 12]. Notably, Microsoft Power BI can effectively manage large datasets, a critical factor in the context of data-intensive manufacturing processes.

- In a survey conducted by Dresner Advisory Services in 2020, it was found that Tableau was the preferred data visualization tool among manufacturers, earning a satisfaction rate of 89 percent [13]. Microsoft Power BI was a close second, demonstrating a

satisfaction rate of 87 percent among the surveyed manufacturers. This data underscores the dominance of these two tools in the manufacturing sector and their high level of usability for data visualization tasks.

- A report by Markets and Markets [14], a market research firm, predicts that the data visualization market for the manufacturing industry will grow at a CAGR of 11.5 percent from 2020 to 2025, and Tableau and Microsoft Power BI are among the key players in this market.
- According to Gartner's Magic Quadrant for Analytics and Business Intelligence Platforms [15], Tableau and Microsoft Power BI are both considered to be leaders in the data visualization market, based on their ability to execute and completeness of vision.
- In a 2019 survey by the Data Warehouse Institute (TDWI), Tableau and Microsoft Power BI were among the top five most widely used data visualization tools among manufacturers.
- According to a report by Research And Markets, Tableau is considered to be the market leader in data visualization software and Microsoft Power BI is considered to be the second most widely used data visualization tool after Tableau.

The evidence presented indicates that both Tableau and Microsoft Power BI hold significant esteem among manufacturers for data visualization tasks [16]. Both tools, renowned for their user-friendly interfaces and capability to manage substantial datasets, offer a comprehensive range of data connectors, making them apt for the multifaceted needs of the manufacturing sector. However, the selection of the most appropriate tool should be contingent upon the specific requirements of the manufacturing entity, the competencies of the personnel, and the available budget. Therefore, it is imperative to thoroughly evaluate the functionality of each tool and ensure that they align effectively with the enterprise's particular use-cases and objectives prior to committing to a decision.

Data Visualization model for manufacturing sector and opportunities for new research

There are several data visualization models that have been used in the manufacturing sector in past research. Some examples include [17, 18]:

- a) Gantt chart: A type of bar chart that is commonly used to represent project schedules, showing the start and finish times of tasks, and their dependencies.
- b) Pareto chart: A chart that combines a bar graph with a line graph, used to identify the most important factors contributing to a particular problem or phenomenon.
- c) Control chart: A chart that is used to monitor the quality of a process over time, with the goal of identifying any variations or trends that may indicate a problem with the process.
- d) Fishbone diagram: Also known as an Ishikawa diagram, this type of diagram is used to identify the root cause of a problem by identifying various factors that may be contributing to the problem.
- e) Heatmap: A type of chart that uses color to represent data values, with different colors representing different ranges of values. This can be used to identify patterns and trends in large datasets.
- f) Scatter plot: A graph that uses dots to represent values for two numeric variables. It can be used to find relationships between variables and identify trends.
- g) 3D visualization: it is becoming increasingly popular in the manufacturing sector as it allows to visualize the data in 3-dimensional space. This can be used to identify patterns, trends and outliers in large datasets.
- h) Dashboard: A visual representation of data that is easily accessible and understandable. Dashboards can be used to display key performance indicators, monitor progress, and identify areas for improvement.

In the manufacturing field, some potential areas of focus for a new research in data visualization could include [19]:

- Developing new methods for visualizing and analyzing large amounts of sensor data from manufacturing processes and equipment, to improve process control and identify inefficiencies.
- Investigating the use of virtual and augmented reality for visualizing and interacting with data in manufacturing environments, such as for training, process design, or quality control.

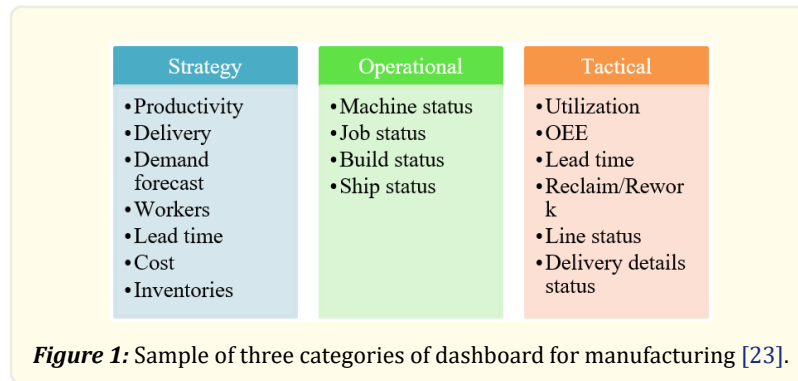
- Examining the use of data visualization in supply chain management, such as visualizing logistics data to optimize transportation routes and inventory levels.
- Developing new visualization techniques for multivariate data, such as data from process control systems and sensor networks, to improve the ability of operators and managers to monitor and optimize production.
- Examining the use of data visualization in predictive maintenance, such as visualizing sensor data to identify potential equipment failures before they occur.
- Investigating the use of data visualization in the field of Industry 4.0 and Smart Factory, to improve the ability of humans to interact with and understand the complex systems that underpin modern manufacturing environments.

Dashboard design for Data Visualization

Scholarly investigations concerning data visualization dashboard design within the manufacturing sector predominantly concentrate on the development of efficient and user-friendly interfaces for the monitoring and analysis of production data. This research encompasses explorations into optimal layouts, visualizations, and data presentations specifically tailored for manufacturing data. Additionally, it delves into the challenge of crafting dashboards that can be seamlessly comprehended and operated by employees lacking technical expertise [20, 21]. Concurrently, additional scholarly investigations have been conducted on the application of data visualization dashboards in enhancing decision-making processes, amplifying efficiency, and curtailing operational costs within manufacturing operations. The overarching aim of these research endeavours is to bolster the capacity of manufacturers to utilize data effectively, thereby facilitating more insightful observations and superior business decisions. Noteworthy variables that warrant consistent monitoring via a data visualization dashboard within the manufacturing sector include [10]:

1. Production efficiency: This includes metrics such as machine uptime, production rate, and yield.
2. Quality: This includes metrics such as scrap rate, rework rate, and number of defects.
3. Maintenance: This includes metrics such as machine downtime, scheduled maintenance, and equipment failures.
4. Inventory and logistics: This include metrics such as inventory levels, lead times, and delivery performance.
5. Energy consumption: This includes metrics such as energy consumption per unit of production, power usage effectiveness, and energy costs.
6. Safety: This includes metrics such as accident rate, near misses, and incidents report.

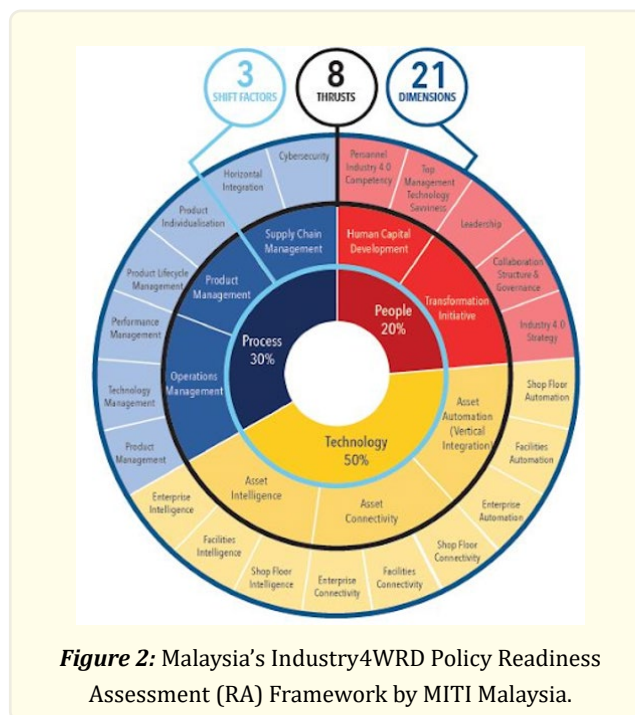
It's worth noting that each manufacturing facility will have different priorities and different factors that influence their operations, so the most important variables to monitor will vary depending on the specific organization. A typical manufacturing dashboard might include a combination of visualizations such as line charts, bar charts, and pie charts to display metrics like production efficiency, quality, and inventory levels. It could also include gauges, dials, or other types of visualizations to display real-time data such as machine uptime and energy consumption [22]. Additionally, the dashboard should be designed in a way that makes it easy to understand and use, with clear and concise labels, and the ability to drill down into the data for more detailed information [11]. It's also important to keep in mind that the dashboard should be customizable, allowing users to select the metrics and data that are most relevant to them. It's also important to have the ability to filter and segment the data based on different dimensions like time, location, and equipment type. Figure 1 shows a sample of the manufacturing dashboard using Tableau incorporating all the above key elements. Overall, the design of a data visualization dashboard for manufacturing should be tailored to the specific needs of the organization and its operations, while also being user-friendly and easy to navigate which can include the strategy, tactical and operational focus area [23].



Research Methodology

The current state of Industry 4.0 adoption manufacturing sectors in Malaysia at post COVID-19 pandemic - Part I

The COVID-19 pandemic has accelerated the adoption of Industry 4.0 technologies and practices in many countries, as businesses have had to adapt to the challenges posed by the pandemic, such as social distancing and remote work. In Malaysia, the government has announced plans to accelerate the adoption of Industry 4.0 technologies, such as automation and data analytics, in order to improve the competitiveness of its manufacturing sector. The Government of Malaysia has announced plans to accelerate the adoption of Industry 4.0 technologies and practices in the country. In 2020, the Ministry of International Trade and Industry (MITI) of Malaysia has launched the “Industry4WRD” (Industry 4.0 National Policy) which aims to increase the adoption of Industry 4.0 technologies and practices in the manufacturing sector, to improve the competitiveness of the sector and to create high-value jobs. The government of Malaysia is also providing financial incentives and training programs to support the adoption of Industry 4.0 technologies. Figure 2 shows the overall Industry4WRD framework focusing on the Industry 4.0 readiness assessment programs.



The key objective if this research is to understand the current baseline of the manufacturing sectors in Malaysia in term of the following three key research questions and subjects;

1. What is the impact of COVID-19 pandemic towards the Industry 4.0 adoption and awareness?
2. What is the key Industry 4.0 technology pillar which getting most response due to the COVID-19 pandemic?
3. Which area to apply the Industry 4.0 technology to fix the problem at the manufacturing area?

A survey has been conducted by sending to the targeted group which mostly the manufacturing players in Malaysia through various channels and platform using the Google Form online. The survey is divided into four main components as shown in Table 1.

Research questions to establish current baseline	Total Questions
Demographics breakdown	3
Industry 4.0 technology adoption	5
COVID-19 Impact	3
Post COVID-19 strategy	2
Others (Not in scope)	1

Table 1: Survey data collection structure.

No	Questions	Answer / Options
1	Company Profile	1. SME 2. LLCs 3. MNCs 4. Others
2	Your position in the company	1. Founder/C-Level/MDs 2. Director 3. Management 4. Executive 5. Others
3	Total Employees	1. 1-20 2. 21-50 3. 51-70 4. 71-100 5. 101 and above
4	How has your perception of Industry 4.0's value changed since the COVID-19 pandemic?	1. Industry 4.0 is more valuable 2. Industry 4.0 value is unchanged 3. Industry 4.0 is less valuable
5	Which one below represent your current company's situation?	1. Business recovering but facing labor shortage 2. Business not recover and over staffing 3. Business not recover and facing labor shortage
6	What is the state of Industry 4.0 implementation at your organization now?	1. Scaled industry 4.0 successfully 2. Stuck in pilot purgatory 3. Have plan but not started 4. No plan to start 5. Never heard about Industry 4.0 and don't know anything about it

7	What are the biggest challenges facing by your company in implementing Industry 4.0 solutions in the current environment?	<ol style="list-style-type: none"> 1. Lack of funding because of the COVID-19 pandemic 2. Hard to justify the ROI 3. Limited understanding of technology and vendor landscape 4. Lack of people, skills and knowledge 5. Data security concerns 6. Never heard about Industry 4.0 before and would like to know more about it 7. Industry 4.0 is not our key focus and will never adopt it
8	What are the biggest pain-points in your manufacturing supply chain operation right now	<ol style="list-style-type: none"> 1. Low Process Yield issues 2. Very high unplanned machine breakdown 3. Hard to manage the inventory 4. Attendance & tardiness of human resource
9	How much percentage of your manufacturing process already been fully automated	<ol style="list-style-type: none"> 1. 0% 2. 1% to 10% 3. 11% to 20% 4. 21% to 30% 5. 31% to 40% 6. 41% to 50% 7. 51% and above
10	What would be the most valuable to your management team within the net 12 mth during this post pandemic phase	<ol style="list-style-type: none"> 1. Venture into new business opportunities created directly or indirectly by the pandemic 2. Better understanding of how customer's needs and habits are changing during and after the pandemic 3. A good model for remote/hybrid work for the organization 4. Alignment in the leadership team on how to view remote work and lead remotely 5. Access to better technology to facilitate remote work for the organization 6. Others
11	Which activity is most challenging for your management team as a whole	<ol style="list-style-type: none"> 1. Internal alignment & cooperation 2. Cascading strategy & initiatives 3. Applying technology to lead people 4. Effective meetings 5. Execution 6. Managing people mindset, culture, attitude and behavior 7. Other
12	Which Industry 4.0 technology pillars do you think will be the top priority to be adopted learning from the challenges facing during COVID-19 pandemic?	<ol style="list-style-type: none"> 1. Real-Time Data Visualization Dashboard 2. Internet of Things (IoT) 3. Augmented Reality 4. Artificial Intelligence (AI) 5. Autonomous Robot 6. Manufacturing Execution System (MES) 7. Cloud Computing

13	What time frame do you expect for full recovery of your manufacturing and supply chain operations after the COVID-19 pandemic	<ol style="list-style-type: none"> 1. Already fully recovered 2. 2-3 mth 3. 4-6 mth 4. 7-11 mth 5. 12-24 mth 6. Beyond 24 mth
14	Let me know if you have any feedback or comments. Thanks	<ol style="list-style-type: none"> 1. Comments required (Optional)

Table 2: Survey questionnaires and answer options.

The Google Form has been distributed to the targeted group within Malaysia by leveraging multiple channels and platform as shown in Table 3.

Channel/Platform	Total contact in databases
WhatsApp's contact	100
Email contact	300
Post in Facebook Page	100
Post in LinkedIn profiles	13000
Agencies (MPC, MY4IRC, SMECorp)	20000

Table 3: Google Form distribution plan.

Data analysis tools - Part II

Once a Google Form is shared and responses start coming in, the data can be collected and analyzed in the following ways:

1. Viewing responses: The responses to the form can be viewed in real-time by going to the "Responses" tab of the form. This tab shows a summary of the responses, including a graph of the responses for each question.
2. Exporting responses: The responses can be exported as a spreadsheet for further analysis by clicking on the "More" button in the "Responses" tab and selecting "Export."
3. Using Google Sheets: The responses can be automatically added to a Google Sheets spreadsheet for analysis by enabling the "Link to spreadsheet" option in the "Responses" tab.
4. Using third-party tools: There are many third-party tools available that can be used to analyze the data from a Google Form, such as Tableau, Power BI, and Excel.
5. Google Form add-ons: Google Form have many add-ons which can also be used to analyze the data, such as Flubaroo, FormMule, FormRanger, and more.

All the above steps help the users to analyze the response of the Google Form in a detailed manner and makes it easy for the user to extract useful insights from the data. In this research a combination of both option 2 and 4 have been chosen by exporting it into excel analysis tools to plot the results into pie-chart and bar-chart to show the results and making the comparison of the responses.

Results and Discussions

The overall results and discussion are structured according to the previous Table 1 structure in order to systematically analyze the overall responses and comparing the results.

Overall Demographics survey's results and analysis

The Table 4 presents the demographic breakdown of 80 survey respondents. The data shows that Multinational Corporations (MNCs) made up 60 percent of the total respondents, Small and Medium Enterprises (SMEs) made up 25 percent, and Local Large Companies (LLCs) and other companies made up the remaining 15 percent. Despite various efforts to increase participation from SMEs in the survey, the data suggests that they are less responsive and less aware of the importance of providing input towards the future improvement of the industry compared to MNCs. The high participation rate of MNCs can be attributed to their larger resources and capabilities to engage in such surveys, however, it highlights the need to further educate and encourage SMEs to participate and provide valuable insights to improve the industry as a whole.

Question No	Total respondent	%	Pie-Chart
No 1			
SMEs	20	25.00%	
LLCs	4	5.00%	
MNCs	48	60.00%	
Others	8	10.00%	
Total	80		
No 2			
Founder/ C-Level/MDs	16	20.00%	
Director	4	5.00%	
Management	32	40.00%	
Executive	12	15.00%	
Others	16	20.00%	
Total	80		
No 3			
1 to 20	8	10.00%	
21 to 50	8	10.00%	
101 and above	64	80.00%	
Total	80		

Table 4: Demographics breakdown of the survey's respondents.

COVID-19 impact to manufacturing operation survey's results and analysis

The summary of the second element of the survey is summarized in Table 5. Question number 4 is the most important subject to analyze in order to answer the research question number 1. The reason why 75 percent of respondents in the survey may have said that Industry 4.0 is more valuable post-Covid-19 pandemic could be due to a number of factors such as:

- The pandemic has highlighted the need for remote work and automation, leading to an increase in the use of technologies such as cloud computing, big data analytics, and the Internet of Things (IoT) which can enable remote work and help businesses to continue operating during a crisis.
- The pandemic has also accelerated the digital transformation of businesses, with many companies investing in Industry 4.0 technologies to improve their operations, increase efficiency, and reduce costs.
- The pandemic has also had a negative impact on the economy, leading to financial difficulties for many businesses. Industry 4.0 technologies can help businesses to reduce costs and increase efficiency, which can be particularly beneficial in a difficult economic environment.
- The pandemic has also led to supply chain disruptions, which have made it difficult for businesses to access the necessary components and equipment to implement Industry 4.0 technologies. Industry 4.0 technologies can help businesses to improve their supply chain resilience and reduce their dependence on a single supplier.

The remaining 25 percent of respondents who think that the value of Industry 4.0 has remained unchanged post-Covid-19 pandemic may have a few reasons for this perception. Some possible explanations could be:

- They may already have been utilizing Industry 4.0 technologies and processes prior to the pandemic, and thus, they may not have seen a significant increase in value after the pandemic.
- They may not have felt the need to adopt Industry 4.0 technologies as their business model or operations may not have been affected by the pandemic.
- They may not have had the financial resources or capabilities to adopt Industry 4.0 technologies due to the economic impact of the pandemic.
- They may not have seen the direct benefits of Industry 4.0 technologies on their operations or may not be aware of the potential benefits that Industry 4.0 could bring to their business.
- They may not have understood the full potential of Industry 4.0 technologies and their applications in their specific industry or sector.

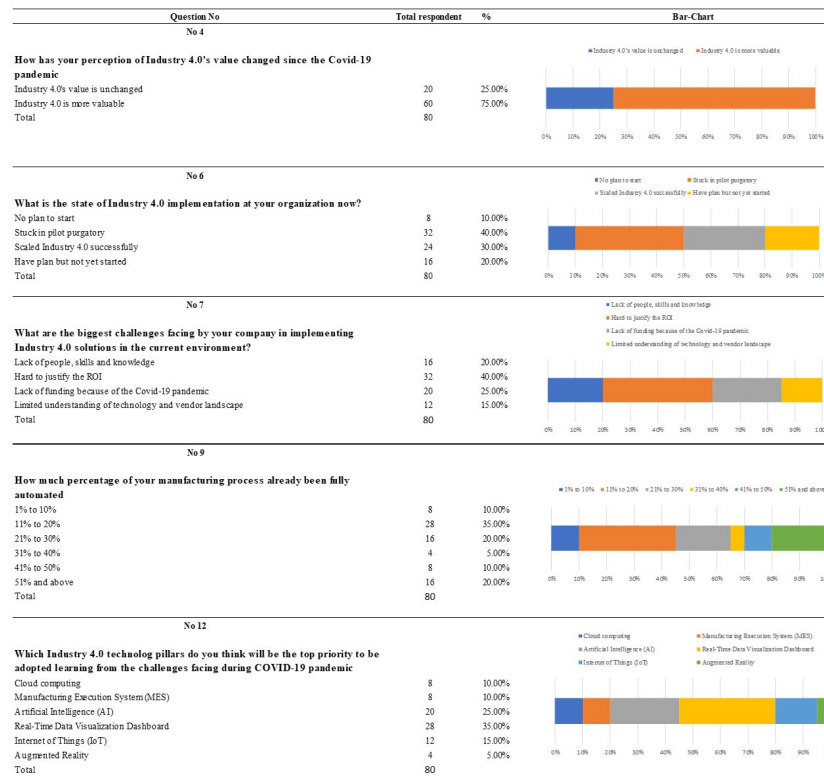


Table 5: Industry 4.0 technology adoption response from respondents.

As far as the Industry 4.0 adoption is concerned, the majority of respondents in the survey stating that they are now stuck in pilot purgatory as far as Industry 4.0 implementation is concerned, could be due to a number of factors such as:

- Difficulty in scaling up and fully implementing Industry 4.0 technologies and processes across the organization.
- Limited resources, such as budget or personnel, to fully implement Industry 4.0.
- Technical difficulties or compatibility issues with existing systems and infrastructure.
- Lack of clear roadmap or strategy for implementation.
- Resistance from employees or other stakeholders who are not familiar or comfortable with the new technologies and processes.

For question number 12, the results from the survey as shown in table 5, provide the answer to research question number 2. In the manufacturing sector, real-time data visualization dashboards can help companies to better respond to the challenges posed by the COVID-19 pandemic. Some issues that can be addressed through real-time data visualization include:

1. **Supply Chain Disruptions:** Real-time data visualization dashboards can help companies to quickly identify and respond to disruptions in their supply chain. By visualizing data on supplier performance, inventory levels, and delivery schedules, companies can identify potential bottlenecks and take action to mitigate them.
2. **Production Monitoring:** Real-time data visualization dashboards can help companies to monitor production processes in real-time. This can help to identify and resolve issues with machinery, workers, or processes, which can improve efficiency and reduce downtime.
3. **Quality Control:** Real-time data visualization dashboards can help companies to monitor and control the quality of their products. By visualizing data on production processes, materials, and finished products, companies can identify and resolve issues that may affect the quality of their products.
4. **Predictive Maintenance:** Real-time data visualization dashboards can help companies to predict when equipment or machinery is likely to fail, so they can schedule maintenance before an equipment failure happens.

Overall, Real-time data visualization dashboards can provide a wealth of insights into how a manufacturing operation is functioning and can help companies respond quickly to issues that arise, which could be beneficial during the pandemic, where supply chain disruptions and production downtime could cause even more damage.

Managing inventory and improving process yield are important issues for the manufacturing sector in the post-COVID-19 pandemic for several reasons:

1. **Managing Inventory:** The COVID-19 pandemic has caused significant disruptions to supply chains, making it difficult for companies to predict demand and maintain adequate inventory levels. Real-time data visualization can help companies to identify and respond to these disruptions, allowing them to better manage their inventory levels and avoid stockouts or overstocking.
2. **Improving Process Yield:** During the pandemic, many manufacturing companies had to operate with reduced capacity or staff, which can lead to increased downtime and decreased efficiency. Improving process yield can help companies to increase productivity and reduce costs, which is particularly important in an economic downturn. Real-time data visualization can help companies to identify and resolve issues that are causing decreased efficiency, such as bottlenecks in production processes or quality control issues.
3. **Economic downturn:** As a result of the pandemic, many companies are facing economic downturns and are looking for ways to reduce costs and increase efficiency. Improving process yield and managing inventory can help companies to reduce costs and increase revenue, which is essential for survival in a downturn.
4. **Consumer behavior:** The pandemic has changed consumer behavior, for example, e-commerce has seen a significant increase, which in turn affects the inventory management, where it's important to have a real-time data visualization to track the order and delivery of the products.

COVID-19 impact to manufacturing operation survey's results and analysis

In order to address the research questions number 3, the results from the survey in Table 6 for question number 8 shows that the combined of how to manage the inventory and low process yield issues with a total of 70 percent of the respondents choose this answer. Managing inventory and improving process yield are important issues for the manufacturing sector in the post-COVID-19 pandemic as they can help companies to better respond to supply chain disruptions and increase productivity and efficiency, which is important for survival in an economic downturn. Industry 4.0 technology, specifically real-time data visualization dashboards, can address and solve the issues of managing inventory and improving process yield in several ways:

1. **Managing Inventory:** Industry 4.0 technology, such as the Internet of Things (IoT) and sensor-based monitoring, can provide real-time data on inventory levels and supplier performance. This data can be visualized on a dashboard, allowing companies to quickly identify and respond to disruptions in their supply chain. For example, an IoT sensor on a warehouse shelf could send data on stock levels to a dashboard, alerting a company when stock is running low and when to reorder.
2. **Improving Process Yield:** Industry 4.0 technology, such as machine learning and advanced analytics, can help companies to identify and resolve issues that are causing decreased efficiency in their production processes. Real-time data visualization dashboards can be used to monitor and analyze data from production processes and equipment, allowing companies to identify bottlenecks, quality control issues, or other problems that are affecting yield. For example, a dashboard could monitor and analyze data from a production line, providing insights on how to optimize the production processes, predict when a machine is about to fail, and plan for preventive maintenance.
3. **Predictive Maintenance:** Industry 4.0 technology, such as Machine learning, can help to predict when equipment or machinery is likely to fail, so they can schedule maintenance before an equipment failure happens. This can help to improve the overall availability of the equipment and reduce downtime which is an important factor for improving process yield.
4. **Automation:** Industry 4.0 technology, such as robotics and automation, can help companies to increase productivity and efficiency. Automated systems can be integrated with real-time data visualization dashboards, allowing companies to monitor and control the performance of these systems in real-time.

Therefore, the Industry 4.0 technology, specifically real-time data visualization dashboards, can help companies to manage inventory, improve process yield, and reduce downtime by providing real-time data and insights on production processes, inventory levels, and equipment performance.

From the survey on question number 5, 80 percent of the respondent responded that their business is now recovering of the COVID-19 pandemic but facing labor shortage. The COVID-19 pandemic has led to a labor shortage in the manufacturing sector in Malaysia for several reasons:

1. **Border closures and travel restrictions:** The pandemic has led to border closures and travel restrictions, which have made it difficult for companies to recruit and bring in foreign workers. Many of the workers in the manufacturing sector in Malaysia are foreign workers, and the inability to bring them in has caused a shortage of labor.
2. **Quarantine and isolation requirements:** The pandemic have led to quarantine and isolation requirements for people who have been in contact with infected individuals or who have traveled to certain areas. This has made it difficult for companies to maintain a stable workforce, as workers may need to be quarantined or isolated at short notice.
3. **Health concerns:** The pandemic has led to health concerns among workers, which has led to some workers choosing not to work, particularly in sectors where social distancing is difficult to maintain.
4. **Economic downturn:** The pandemic has led to an economic downturn, which has led to a decrease in demand for goods, which in turn has led to a decrease in the need for labor in the manufacturing sector.
5. **Social distancing measures:** The pandemic has led to social distancing measures, which has led to a decrease in the number of workers that can be accommodated in a given space, which has led to a decrease in labor.
6. **Government policies:** Government policies such as the Movement Control Order (MCO), which was implemented to curb the spread of the virus, have forced factories to close or operate at a reduced capacity, which has led to a decrease in the need for labor.

The final question number 11 from Table 6 that managing people's mindset, culture, attitude, and behavior is the most challenging activity currently for manufacturers in Malaysia to manage during the COVID-19 post-pandemic recovery may be due to several reasons:

1. **Change in work environment:** The pandemic has led to changes in the work environment, such as remote work, social distancing measures, and increased use of technology. These changes have required employees to adapt to new ways of working, which can be challenging for some people.

2. Stress and anxiety: The pandemic have led to stress and anxiety among employees, which can affect their attitude and behavior. For example, employees may be worried about their health and the health of their loved ones, which can lead to decreased motivation and productivity.
3. Economic uncertainty: The pandemic has led to an economic downturn, which can lead to uncertainty and insecurity among employees, which in turn can affect their attitude and behavior.
4. Remote work: The pandemic has led to an increase in remote work, which can make it difficult for managers to maintain a sense of team cohesion and to manage employee behavior effectively.
5. Limited physical interaction: The pandemic has limited physical interactions between employees, which can make it difficult to maintain company culture and to manage employee behavior effectively.
6. Different coping mechanisms: People have different coping mechanisms, some may have been able to adapt to the new norm and others may have been struggling, this can affect the attitude and behavior of employees
7. Managing mental health: The pandemic has led to an increase in mental health issues, which can affect the attitude and behavior of employees. Employers may need to provide support for employees who are struggling with mental health issues, which can be challenging.

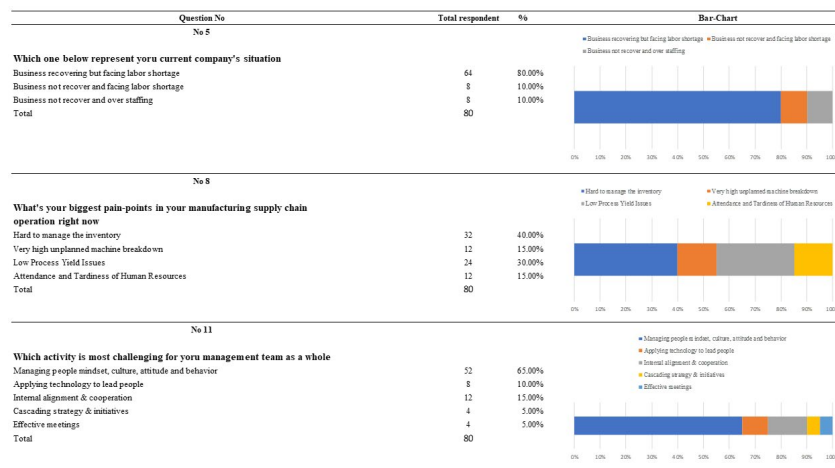


Table 6: COVID-19 impact to manufacturing operation.

Post-COVID-19 Strategy survey results and analysis

The final phase of this research is to analyze the survey results related to the response from the manufacturers on their post-COVID-19 recovery plan and timeline. From the results in Table 7, it shows that 30 percent of the respondent feels that the most valuable activity to focus in the next 12 month is to have a better understanding of how customer’s needs and habits are changing during and after the pandemic. It follows by access to better technology to facilitate remote work for the organization and venture into new business opportunities create directly or indirectly by the COVID-19 pandemic. A few factors which could lead to this discovery as follow;

1. Understanding customer needs and habits: The COVID-19 pandemic has caused significant changes in consumer behavior, which may have altered their needs and habits. By understanding these changes, manufacturers in Malaysia can better adapt their products and services to meet the new demands of the market, allowing them to remain competitive in the post-pandemic market.
2. Access to better technology to facilitate remote work: Remote work has become increasingly important due to the pandemic, and access to better technology can help manufacturers in Malaysia to facilitate remote work for their employees, which may increase productivity and efficiency, while also allowing them to adapt to the new normal.
3. Exploring new business opportunities created by the COVID-19 pandemic: The pandemic has created new business opportuni-

ties, either directly or indirectly, and manufacturers in Malaysia may be able to capitalize on these opportunities by exploring them, this could be diversifying their products or services and creating new revenue streams. This could be beneficial for the manufacturer in the long run and help them to navigate through the uncertainty of the post-pandemic market.

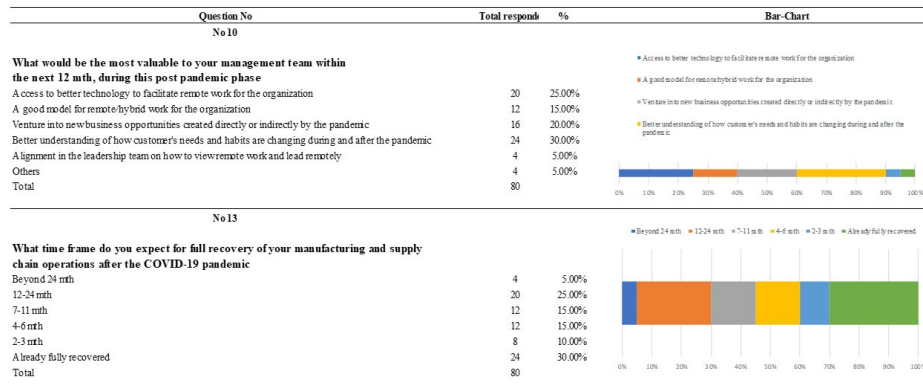


Table 7: Post COVID-19 strategy.

The last question from the survey is to understand the time taken for the full recovery from each respondent where 30 percent responded that they already fully recovered while another 25 percent think that they need another between 12 to 24 month. The survey results indicate that 55 percent of manufacturers in Malaysia have either fully recovered or are in the process of recovering from the impact of the COVID-19 pandemic. The 30 percent of respondents who claim to have fully recovered suggest that these manufacturers have been able to adapt and find ways to continue operating during the pandemic, possibly through a shift to e-commerce, remote work, or diversifying their products or services. The 25 percent of respondents who claim they still need between 12 to 24 months to recover suggests that these manufacturers are still facing significant challenges and have not been able to fully adapt to the new market conditions caused by the pandemic. This could mean they have been impacted more severely or they may have less resources to adapt. These manufacturers may need to implement additional measures to help them recover, such as cost-cutting measures, new business strategies or government support. The key factors that could contribute to the above survey results of Malaysia manufacturers recovery from the COVID-19 impact are:

1. **Adaptability and flexibility:** Manufacturers who have fully recovered or are in the process of recovering may have been able to adapt and find ways to continue operating during the pandemic, possibly through a shift to e-commerce, remote work, or diversifying their products or services.
2. **Resources:** Manufacturers who are still facing significant challenges and have not been able to fully adapt to the new market conditions may have less resources to implement measures that could help them recover, such as cost-cutting measures, new business strategies or government support.
3. **Industry sector:** Manufacturers in certain sectors may have been more impacted by the pandemic than others, and therefore may have a harder time recovering.
4. **Location:** Manufacturers in certain regions may have been more impacted by the pandemic than others, and therefore may have a harder time recovering.
5. **Sample size:** The survey sample size may not be representative of the whole Malaysia manufacturers, so the results may not reflect the reality.

Conclusions

COVID-19 pandemic impact towards the Industry 4.0 adoption and awareness

This research study is useful in understanding the impact of the COVID-19 pandemic towards the adoption and implementation of

the Industry 4.0 among the Malaysia's manufacturers. The analysis of the survey's results summarizes the following answer to the research question;

- The COVID-19 pandemic has highlighted the importance of Industry 4.0 technologies in enabling manufacturers to better respond to disruptions and maintain business continuity. However, many manufacturers in Malaysia may still be in the pilot purgatory phase, meaning they have not fully implemented these technologies or are still experimenting with them.
- There are several reasons why manufacturers in Malaysia may be stuck in the pilot purgatory phase. One reason is lack of understanding or knowledge about Industry 4.0 technologies and their potential benefits. Another reason may be lack of financial resources or investment to fully implement these technologies. Additionally, there may be concerns about the complexity and cost of integrating Industry 4.0 technologies into existing systems and processes.
- To take advantage of this opportunity and overcome these issues, manufacturers in Malaysia need to invest in developing the necessary skills and knowledge to understand and effectively implement Industry 4.0 technologies. This can include training for employees, as well as partnerships with technology providers and consulting firms.
- Manufacturers also need to invest in the necessary hardware, software and infrastructure to implement Industry 4.0 technologies, such as automation systems, IoT devices and data analytics tools. Additionally, manufacturers need to develop a clear roadmap for implementing Industry 4.0 technologies, including timelines, milestones and success criteria.
- It would be also beneficial for manufacturers in Malaysia to join industry groups, clusters or networks that can provide opportunities for collaboration and knowledge sharing with other manufacturers and Industry 4.0 experts.

Overall, the key to overcoming the issues of the pilot purgatory phase is taking a strategic, holistic approach to Industry 4.0 implementation that includes investment in skills and technology, as well as a clear plan for integrating these technologies into existing systems and processes.

Key Industry 4.0 pillar with highest demand due to the COVID-19 pandemic

Based on the results of this research the real-time data visualization dashboards are the most popular Industry 4.0 technology tools in responding to COVID-19 challenges in the manufacturing sector in Malaysia because they provide a quick and efficient way to identify and respond to disruptions in the supply chain, production processes, and quality control. These dashboards allow companies to monitor their operations in real-time, providing insights into potential bottlenecks and issues that need to be addressed.

Additionally, predictive maintenance capabilities can help companies anticipate equipment failures and schedule maintenance accordingly, reducing downtime and increasing efficiency. Overall, real-time data visualization dashboards provide valuable information that can help companies respond quickly to the unique challenges posed by the COVID-19 pandemic in Malaysia, allowing them to keep their operations running smoothly and effectively.

Some popular and reliable real-time data visualization dashboard tools that Malaysia manufacturers can adopt at post COVID-19 pandemic for lower cost include:

1. Tableau: Tableau is a powerful data visualization tool that allows users to easily create interactive dashboards, charts, and reports. It offers a wide range of data connectors, which makes it easy to connect to various data sources
2. Power BI: Power BI is a business intelligence tool that allows users to create interactive dashboards, charts, and reports. It offers a wide range of data connectors, making it easy to connect to various data sources.
3. Klipfolio: Klipfolio is a cloud-based data visualization tool that allows users to create interactive dashboards, charts, and reports. It offers a wide range of data connectors and it's relatively affordable.
4. Grafana: Grafana is an open-source data visualization tool that allows users to create interactive dashboards, charts, and reports. It's highly customizable, and it's a good option for companies that need to integrate with existing tools and systems.
5. D3.js : D3.js is a JavaScript library for data visualization that allows users to create interactive dashboards, charts, and reports.

It's open-source and it's relatively affordable.

Overall, these tools are popular and reliable options for Malaysia manufacturers that are looking for a lower cost and reliable solution for real-time data visualization post COVID-19 pandemic.

Focus application of the Industry 4.0 technology pillar based on the top priority area

Finally the last research question been answer through this research where the real-time data visualization dashboard Industry 4.0's tools can help Malaysia manufacturers address the top two issues related to inventory management and process yield improvement caused by the Covid-19 post-pandemic effect.

Real-time data visualization dashboard tools can help Malaysia manufacturers to address issues related to inventory management and process yield improvement caused by the Covid-19 post-pandemic effect in several ways:

- **Inventory Management:** Real-time data visualization dashboard tools can help manufacturers to monitor inventory levels in real-time and identify any potential bottlenecks or shortages that may occur. This allows manufacturers to take proactive measures to prevent stockouts and ensure that they have enough inventory on hand to meet demand.
- **Process Yield Improvement:** Real-time data visualization dashboard tools can help manufacturers to monitor production processes in real-time and identify any issues that may be impacting process yield. By visualizing data on production processes, materials, and finished products, manufacturers can identify and resolve issues that may affect the quality of their products.
- **Predictive Maintenance:** Real-time data visualization dashboard tools can also help manufacturers to predict when equipment or machinery is likely to fail, so they can schedule maintenance before an equipment failure happens. This can help to reduce downtime and increase efficiency.
- **Real-time monitoring and analysis of data:** Real-time data visualization dashboard tools can also help manufacturers to monitor and analyze data in real-time. This can help manufacturers to identify patterns, trends, and issues in the data that may not be immediately apparent. By identifying these issues early on, manufacturers can take proactive measures to address them and prevent them from becoming bigger problems.

These tools provide valuable insights and can help manufacturers respond quickly to issues, preventing bigger problems.

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