Implementation Agent: Organiser: Funded by Trade and Industrial Organisation Support Fund, Trade and Industry Department

Guidebook to Excel HKSMEs' Competitive Advantages by Digital LEAN for Building Up the Foundation of Industry 4.0 Enterprises

Foreword

Project Introduction

Introduction of project: To Excel HKSMEs' Competitive Advantages by Digital LEAN for Building Up the Foundation of Industry 4.0 Enterprises

In the face of the increasing number of overseas customers who are implementing "Industry 4.0", Hong Kong companies as suppliers must also upgrade to "Industry 4.0" in order to remain competitive in the international market. To help Hong Kong SMEs move forward and implement "Industry 4.0", the Hong Kong Mould and Product Technology Association (HKMPTA) has partnered with the Hong Kong Productivity Council (HKPC) to launch a project " To Excel HKSMEs' Competitive Advantages by Digital LEAN for Building Up the Foundation of Industry 4.0 Enterprises". Funded by the Trade and Industrial Organisation Support Fund (TSF), the project is to promote the upgrading and transformation of Hong Kong's industrial sector and enhance its competitive edge.

Editorial Board and Disclaimer

Publication:

Hong Kong Productivity Council

HKPC Building, 78 Tat Chee Avenue, Kowloon, Hong Kong

The project is organised by the Hong Kong Mould and Product Technology Association (HKMPTA). The Hong Kong Productivity Council is responsible for implementation and the project is funded by the Trade and Industrial Organisation Support Fund (TSF) of the Trade and Industry Department (TID) of the Government of the Hong Kong Special Administrative Region. Any opinions, research findings, conclusions or recommendations expressed in this publication / in the event (or members of the project team) do not represent the Hong Kong Special Administrative Region Government, the Trade and Industry Department or the Trade and Industrial Organisation Support Fund (TSF).

Organiser and supporting organisation

Organiser:

香港模具及產品科技協會
Hong Kong Mould and Product Technology Association

Implementation organisation:

Funding Support:

工商機構支援基金
Trade and Industrial Organisation Support Fund

Organisation Introduction

<u>The Hong Kong Mould and Product Technology Association (HKMPTA)</u>

Established in May 2005, the Hong Kong Mould and Product Technology Association (HKMPTA), formerly known as Hong Kong Mould and Die Technology Association, is a non-profit-making association registered in Hong Kong. The founding members are prominent mould and product entrepreneurs in Hong Kong, who have grown up within the local industries and have dedicated their careers to the Chinese Economic Reform.

With lofty ideals, HKMPTA aims to upgrade the mould and product technology in Hong Kong, the mainland and the world. By virtue technology power, HKMPTA strives to enhance the technology level of Hong Kong's manufacturing and industrial sectors by promoting creativity and innovation.

With great support from the local industries, we have now amassed many companies as members. The Executive Committee of the HKMPTA comprises of over 20 elites and professionals from the mould and product industries. HKMPTA also gains support from a number of local top industrialists and professionals who have taken up posts as Honorary Presidents and Honorary Advisors of the Association.

Objectives

1. Gather the strengths of the mould and product industries around the world to enhance the exchange of technological information, technology and experience, and to encourage creativity and innovation.
2. To enhance the technology level of local manufacturing sector, in order to impel the rapid development of the manufacturing sectors of both Hong Kong and Mainland to world-class standard.

Mission

1. To strengthen the cooperation with the Ministry of Science around the world and to continue introducing advanced precision manufacturing technologies in fulfilling the needs of nowadays industrial development.
2. To establish close relationship and communication channels with domestic and foreign government agencies, industry and trade organisations, so as to reflect the actual situation of the industry, promote policy advantages and safeguard the rights and interests of the industry.
3. To promote exchanges and cooperation between upstream and downstream industries to enhance the business development opportunities within the mould and product industries.

4. To drive the cooperation and integration between the industries and technology research for the application of the latest technology solutions and continual development of the industries.
5. To liaise with academic institutes for promoting the excellence of the mould and product manufacturing sector among the young generation and to encourage the youth's self-esteem in devoting to the mould and product industries.
6. To organise a series of activities to promote the image and the professionalism of the mould and product industry in Hong Kong and overseas to propel further development opportunities of the sector.

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Section 1: Digital Lean Model

Background

Hong Kong enterprises and those with manufacturing bases in Mainland China face significant challenges from the rise in operating costs and the current global economic situation. With increasing labour costs and limited resources, some large multi-national corporations (MNCs) have upgraded their production technologies to improve efficiency and productivity. However, some Hong Kong manufacturers, especially small and medium-sized enterprises (SMEs), lack the information and resources to develop these strategies to stay competitive.

According to the statistic from Trade and Industry Department (TID), the number of SMEs which conduct business operations in Hong Kong is continuously increasing. The most recent set of statistics shows over 340,000 Hong Kong-based SMEs and over 1 million SME employees, which make up over 98% of all businesses in Hong Kong today.

	No. of SMEs	No. of Employees
Total	> 340 000	> 1 200 000

From the statistic of TRADING ECONOMICS, manufacturing production in Hong Kong increased 5.8% year-on-year in the last quarter of 2021, following a downwardly revised 7.6% rise in the previous period. Output volumes rose mainly for food, beverages and tobacco (10.4%); paper products, printing and reproduction of recorded media (2%); and textiles and wearing apparel (0.5%). On the other hand, production fell for metal, computer, electronic and optical products, machinery and equipment (-1.6%). Considering full 2021, industrial output was up 5.5%, following a 5.8% contraction in 2020 when the coronavirus pandemic hit the economy hard.

To better understand enterprises' needs, the Hong Kong Mould and Product Technology Association (HKMPTA) corporates with the Hong Kong Productivity Council (HKPC) to study the difficulties of SMEs in the manufacturing industry. It is observed that Hong Kong SMEs often lack digital solutions and integrated information when seeking alternative options for their operations. Some of them use a very traditional production line and assembly process by the labour force, and no digital data is collected and utilised in production management. Hong Kong SMEs need specific and practical guidance on the overarching matters related to doing business and how to use Industry 4.0 key technologies in their business to reduce cost and enhance productivity.

This guidebook provides valuable information to address local SMEs' difficulties. It outlines their current situation and operation process in Hong Kong. It highlights the potential solution for them to enhance their operation process and lead them toward the world of Industry 4.0.

Industry Situation and Difficulty

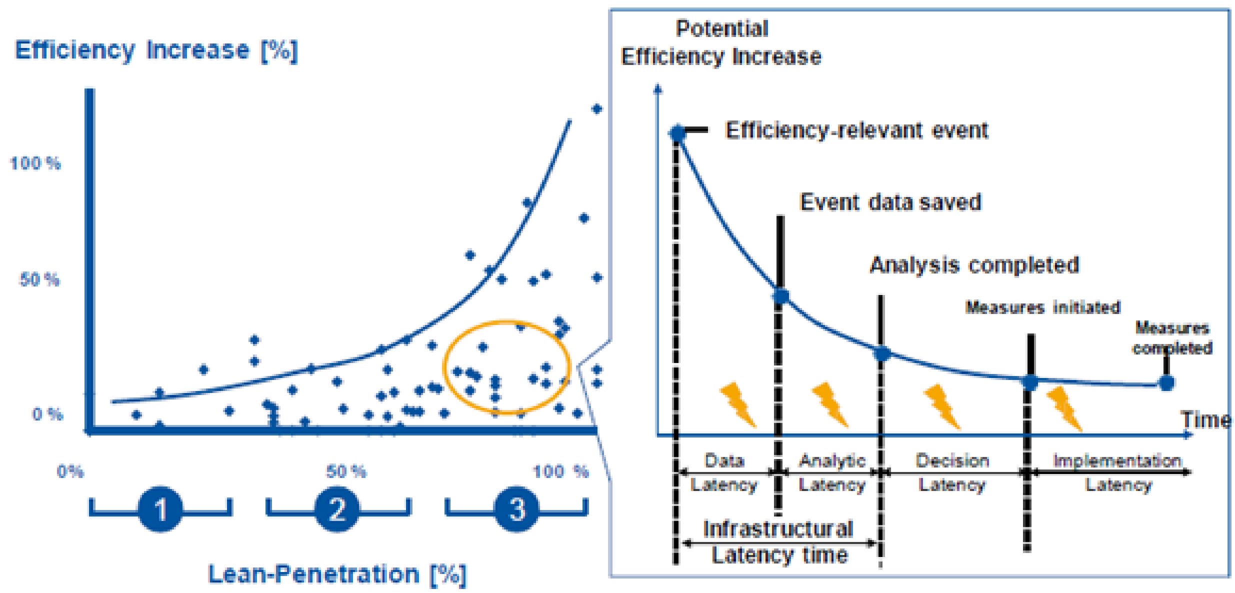
Due to the development of technologies, it came to the Fourth Industrial Revolution era and pushed many manufacturing industries to transform fitting into the Industry 4.0 world. Although automation in manufacturing is highly applied, many SMEs cannot afford to develop or invest in automatic machines and advanced devices due to their business scale and cost concerns. Therefore, many manufacturing industries in Hong Kong still rely on manual operation processes in their business. Even today, manual operation sectors can include everything from toys, apparel, and jewellery to medical devices, consumer electronic products, electrical goods, and automotive components.

Based on the industry experience, it is observed that most manufacturing enterprises currently lack real-time data on the state of equipment performance like utilisation, downtime, Overall Equipment Effectiveness (OEE), energy performance, etc. On the contrary, there is also rare on the labour production line for collecting data on real-time performance like Work-in-Process (WIP) rate, line balancing efficiency, first-pass yield, etc. In most current situations, it is a common practice that still relies on manual data recording, which is not real-time and inaccurate. In this case, if the company would like to improve the operation for higher

efficiency and productivity, due to the slow response of data, the improvement result would not be able to catch up with the rapid change in the market. In current practice, the data is manually recorded, leading to data availability latency—the latency of data collection delays the data analysis, decision making, and implementation. The whole improvement

operation will be delayed, and the efficiency will be affected, which will lead to a slow response to the rapid change market.

As shown in below Figure, there will be latency in data acquisition, analytics, decision, and implementation in current practice due to the data collected through manual recording. Therefore, the potential efficiency will decrease.

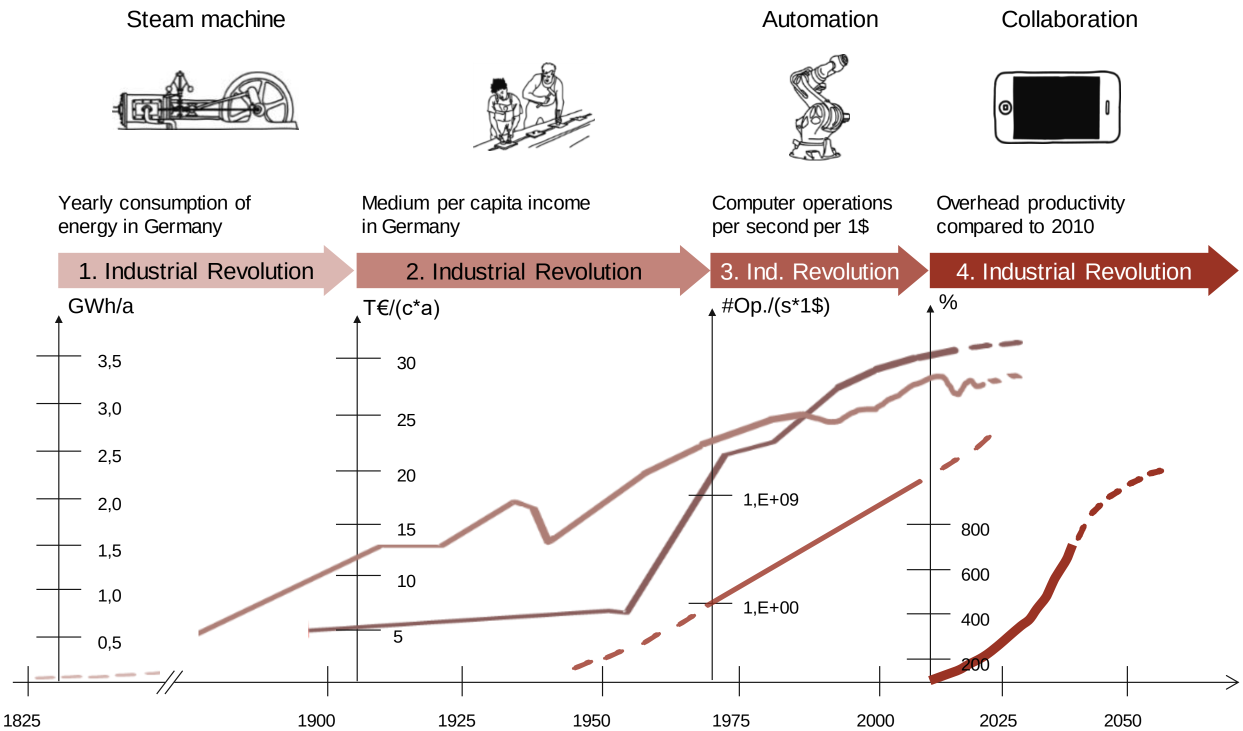


As a result, enterprises need digital solutions to collect real-time data. Digital solutions enable data visualisation and transparency through real-time data acquisition, leading to faster data availability and shorter decision-making latency. Therefore, real-time data availability and transparency could excel the LEAN effectiveness.

Cost and lead-time are always the main concern for SME enterprises to develop the digital solution or apply the Industry 4.0 technologies since they have limited resources and budgets. Also, the long lead time for solution development and solution testing after application will severely affect their business. Therefore, unlike large-scale enterprises, SMEs enterprise needs an easy and fast set-up solution for them in digitalised development.

Concept of Industry 4.0

The term Industry 4.0 is based on the previous global industrial revolutions throughout the last centuries. The commencement of the 1st Industrial Revolution is closely linked to a small number of innovations. Foremost the power machine became suitable and was introduced into industrial use in the second half of the 18th century.



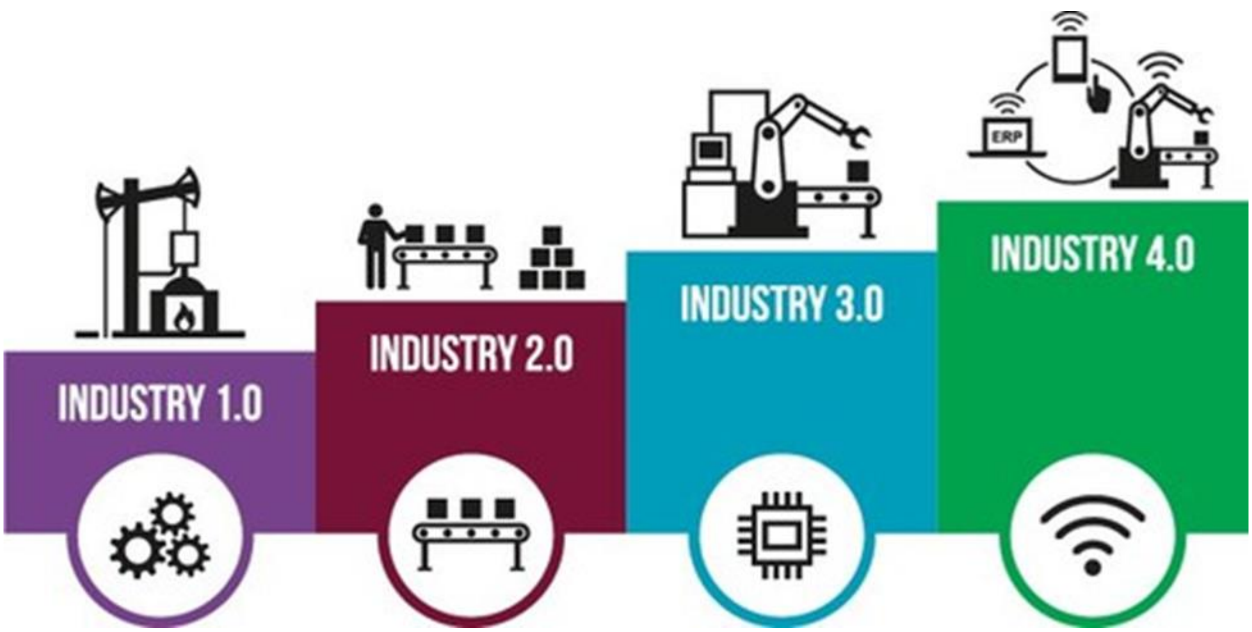
In dependence on: H.-J. Warnecke (1992) Fraktale Fabrik

Effects of the different industrial revolutions

The 2nd Industrial Revolution came with the analysis and optimisation of workflows. Applying science to engineering processes, labour was allocated according to specific process steps (a division of labour).

Productivity increased due to the standardisation of best practices and the elimination of waste.

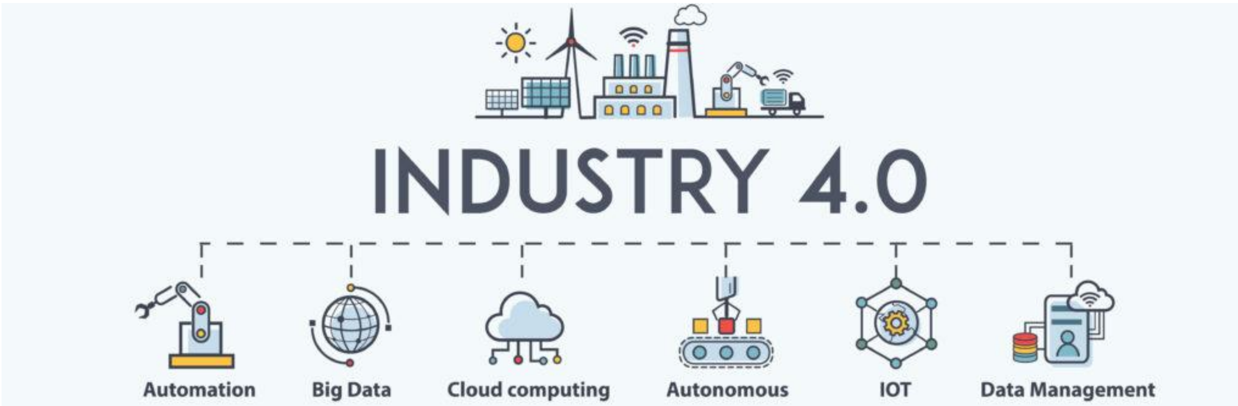
The 3rd Industrial Revolution introduced automation technology into industrial use by the developments of electronics and computers. Production lines were automated with industrial robots and Programmable Logic Controllers (PLC). The 4th Industrial Revolution integrates the physical and digital world in production companies creating value by digital-driven business models and further increase in productivity and efficiency.



Industry 4.0 is driven by recent trends in both the cyber and physical world. The single source of truth is the practice of structuring

information and schemata in a single database. Any possible linkages to the data are established by reference only. The single source of truth is the basis for reliability and consistency in the company data necessary for data analytics and predictions. The digital players in the market drive the cooperation in business and social communities. Information Technology (IT) supports the storage of data in the cloud, provide methods for data mining and high-speed computing. Automation processes by including sensors become highly robust and cost-efficient and provide open IT-Systems. Industry 4.0 fosters collaboration and productivity by improving human/human, human/machine, and machine/machine interfaces.

Industry 4.0 is a new level of organisation and control over the entire value chain of the life cycle of products, and the basis for Industry 4.0 is the availability of all relevant information in real-time by connecting all instances involved in the value chain. The connection of people, things, and systems creates dynamic, self-organising, real-time, optimised, value-added connections within and across companies.



Industry 4.0 does not only concern manufacturing processes in factories, but the concept applies to all operations, including products and services. Technology enables Industry 4.0; however, the selection of the right applications is essential to deliver value to the company. The goal is different from the past, instead of creating new industrial technologies (predictive industrial revolution), but integrating all industry-related technologies, sales, and product experiences. It is to build a smart factory with adaptability, resource efficiency, and ergonomics, and integrate customers and business partners in business processes and value processes to improve production efficiency and achieve smart production. With the advent of the industrial Internet era, Germany's Industry 4.0 practice provides a new path to explore future production. It connects factories, machines, production materials, and people

through network technology, bringing unlimited imagination to industrial intelligence.

Digital technology enables real-time data collection of value-added processes and simultaneous performance analysis within a manufacturing company. The industries in the future will be hyper-connected, “smartified”, and autonomously operated.

The use of digital technologies and the comprehensive networking of objects, devices, and machines in implementing innovative Industry 4.0 solutions also contribute to improvements in the speed of reaction and the resilience of companies to better overcome unexpected developments such as the coronavirus crisis. In addition, real-time networking simplifies operations while maintaining a physical distance.

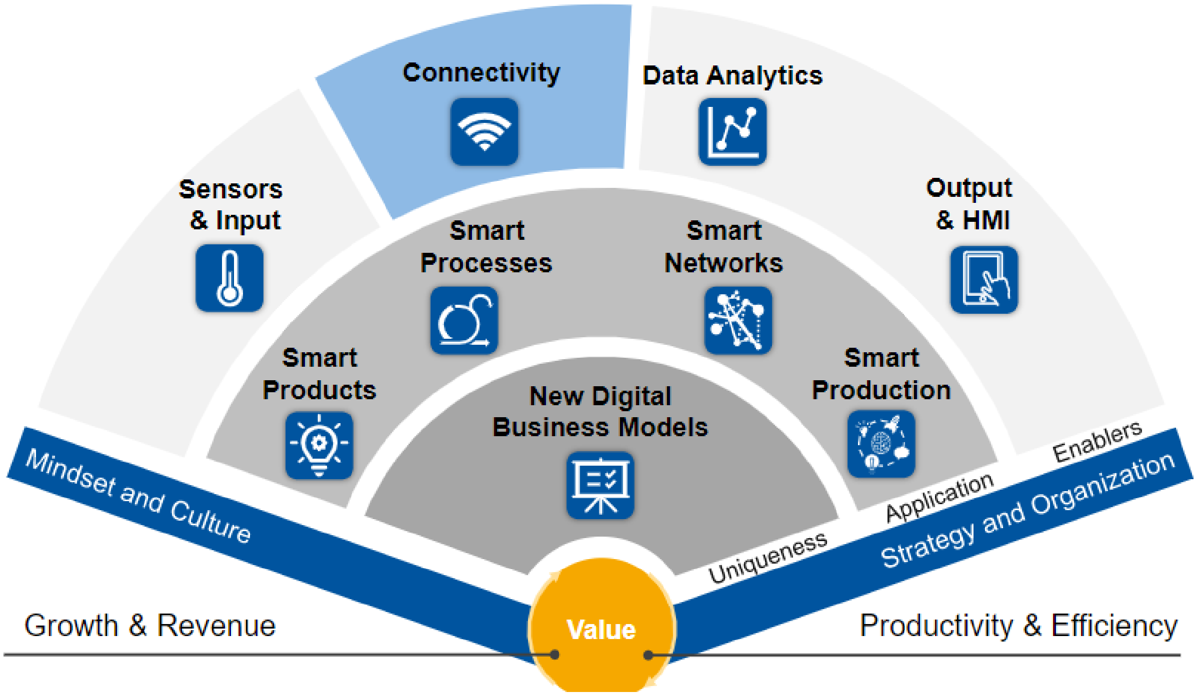
There are four key enabling technologies that Industry 4.0 proposed: **Sensor**, **Network**, **Data Analytics** and **Human Machine Interface (HMI).**

Sensor: Data collection and measurement

Network: Data transformation

Data Analytics: Diagnostic and predictive

HMI: Visualisation and dashboard control



To evaluate the maturity level of Industry 4.0 in the enterprise, the German institute - Fraunhofer Institute for Production Technology (IPT) defined different stages of Industry 4.0 for identifying the Industry 4.0 maturity level of the enterprise. Below is the Industry 4.0 Maturity Index from level (-2i) to level (4i). Under level (0i), the enterprise has not yet reached the fundamental requirement of Industry 4.0.

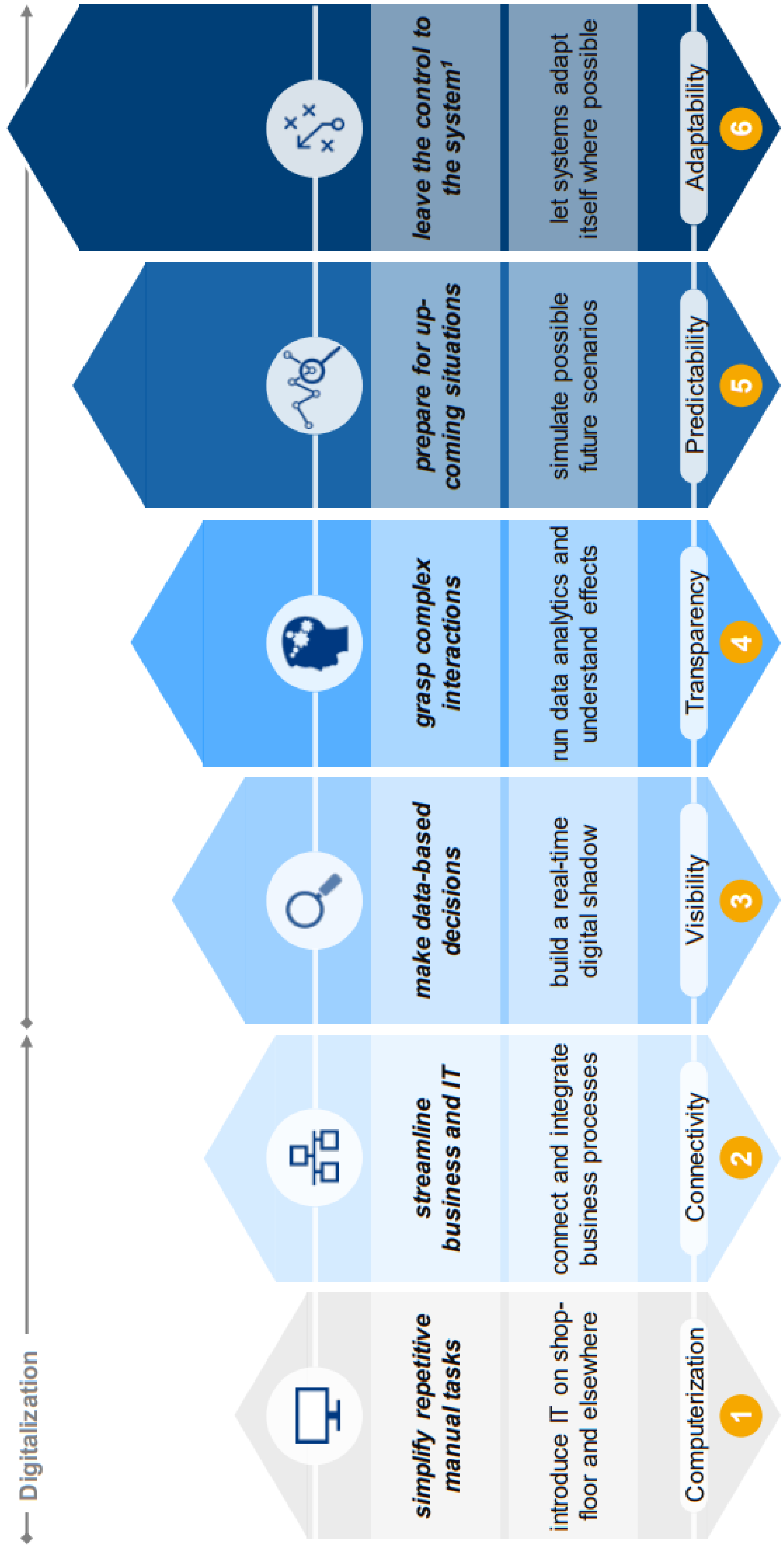
Smart Industry Level			Characteristics & Requirements
4i	i4.0 - Intelligent, Autonomous Processes & Self	Self-optimizing processes and autonomous control	• Autonomous automation (Smartify)

	Organising System (4i)	of product and process along the value chain	• Self-learning, self-organising and self-optimization • Horizontal integration along value chain
3i	i4.0 - Integration of Cyber-Physical System (3i)	Mobile assistance systems and human-machine/ machine-machine collaboration for decentralized decision-making	• Decentralised decision-making • HMI/MMI, Industrial apps • Mobile assistance systems • Close-loop process optimisation
2i	i4.0 - Real-time Data Processing & Integration (2i)	Development of knowledge and insights through the analysis and aggregation of all available	• Full digitalisation & aggregation of real time data • Smart Data analytics

		information and data sources	• Improving forecast ability & decision making
1i	i4.0 - Real-time Data Generation (1i)	Generation and availability of data and information of all activities in real-time	• Vertical integration (Business & Production) - PLM, ERP, APS, SCADA, MES/Sensor in real time data processing • Visualisation and use of data driven actions • Well established "Single Source of Truth"
0i	i4.0 - Frame Condition (0i)	Organisational and infrastructural enablers for the implementation of Industry 4.0	• Industry 4.0 awareness and culture built • IT-infrastructure and data security

			• Data acquisition by sensor and machine IoT (M2M) in real time for process understanding • Digital Lean processes & reasonable automation • Advanced tools adopted & mastered
-1	Industry 3.0	Predominantly Industry 3.0 process (Discrete Automation)	• Discrete automation • Discrete IT system application adopted
-2	Industry 2.0	Predominantly Industry 2.0 process (Division of Labour)	• Strong division of labor • No information technology/system adopted

Source: Developed by Fraunhofer IP T & HKPC, 2015


Digitalization
1
Computerization
introduce IT on shop-floor and elsewhere
simplify repetitive manual tasks
2
Connectivity
connect and integrate business processes
streamline business and IT
3
Visibility
build a real-time digital shadow
make data-based decisions
4
Transparency
run data analytics and understand effects
grasp complex interactions
5
Predictability
simulate possible future scenarios
prepare for up-coming situations
6
Adaptability
let systems adapt itself where possible
leave the control to the system[1]

Industry 4.0 key technologies enhance productivity and efficiency of Hong Kong Industry, and also as a key enabler towards the foundation of Industry 4.0 (0i-1i) and prepare for detailed implementation roadmap for 1i implementation, end-to-end real-time data acquisition, on which is a foundation for next stage 2i Real-time Data Processing & Integration. Industry 4.0 promotes faster, more flexible, and more efficient processes. It could help enterprises speed up OBM/ODM transformation in researching and developing products or prototypes through the digital solution to optimise the New Product Development Process. Furthermore, it could also increase the HKSMEs' professional image and build a solid foundation for industry 4.0 via exhibitions in Hong Kong and Shenzhen. Finally, yet importantly, it could address the market demand for Digital LEAN solutions and problems that HKSMEs are facing.

Lean Concept and Case Examples

Industry 4.0 builds on Lean's foundations in continuous improvement and investigates the importance of digitally transforming manufacturing concepts. The traditional lean concept originated from Japanese automobile manufacturing and has been applied by numerous enterprises for many years to drive efficiency and reduce waste. However, with the Industry 4.0 era, digital technologies have made production and manufacturing more flexible and efficient.

The technologies of connecting devices, sensors, machines, and software enable this rapid data collection in real-time. These changes allow managers to improve processes or predict failures before they occur; meanwhile, machines can automatically optimise themselves, diagnose problems or configure more efficiently. The emergence of this new digital era raises concerns about digital and physical technologies to boost lean production and enable enterprises to embrace digital lean. In this study, digital lean technology will be applied to the manufacturing production line to discover the benefits and challenges of adopting digital lean technologies.

In 1930, Japanese automotive manufacturers pioneered lean production. Its goal is to remove waste across the value chain to optimise waste minimisation and production time. Lean may be used outside of manufacturing in any process-driven situation, independent of industry.

Through indentation, the ultimate objective of lean is to remove or alter the process parts that do not contribute value. (1) non-utilised talent, (2) inventory, (3) motion, (4) waiting time, (5) transportation, (6) faults, (7) over-production, and (8) over-processing are the eight categories of wastes recognised and intended to be eliminated in operation or manufacturing process.

Eight types of waste

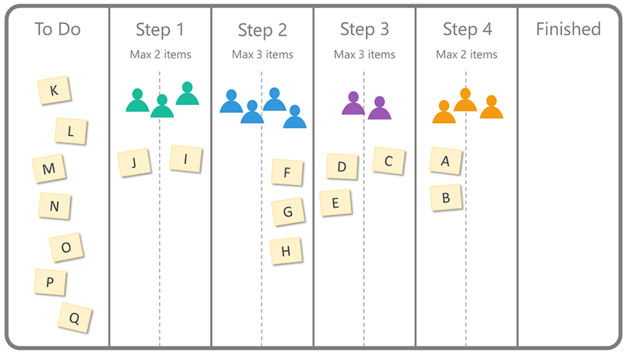
The approach in lean management is to minimise the waste and non-value added activities throughout a process or value chain. Proper lean tools will be applied for completing this approach, such as value stream mapping to identify waste and critical process steps, single-minute exchange of dies reduces equipment downtime that results from tool changeovers, visual controls to help operators place the right times to replenish material or adjust equipment, and preventive maintenance reduces the number of breakdowns by proactively maintaining and controlling equipment at fixed intervals.

The traditional lean involves lots of human operation and analysis, which causes a delay in process improvement and cannot provide quick response or insight. By applying digital technology, digital lean offers quick responses to customer need and leads to fast and robust production, resulting in quality improvement and cost reduction. Below will show an example of lean manufacturing tools.

1. <u>Kanban</u>

Kanban is the manufacturing system that regulates the resource by using an instruction card sent along the production line. It records the consumption of parts or raw materials at the workstation and replenishes it after reaching a certain level. It helps eliminate waste from inventory or overproduction and removes the need for physical inventories instead of relying on signal cards to indicate when more goods need to be ordered. There are six practices of Kanban.

- Visualise workflow
- Limit work in progress (WIP)
- Manage flow
- Make process policies explicit
- Implement feedback loops
- Improve collaboratively



2. <u>Total Productive Maintenance (TPM)</u>

Total Productive Maintenance (TPM) is a system that optimises equipment performance and workflows. It is typically performed periodically based on runtime, cycles, and other criteria to service equipment before a failure. It can create a shared responsibility for equipment that encourages greater involvement by plant floor workers. This can be very effective in improving productivity (increasing uptime, reducing cycle times, and eliminating defects).

Total productive maintenance strives for perfect production.

It aims:

- No breakdowns
- No stops or running slowly
- No defects
- No accidents

Benefits of Total Productive Maintenance	
Direct Benefits	**Indirect Benefits**
Less unplanned downtime resulting in an increase in OEE	Increase in employee confidence levels
Reduction in customer complaints	Produces a clean, orderly workplace

Reduction in workplace accidents	Increase in positive attitudes among employees through a sense of ownership
Reduction in manufacturing costs	Pollution control measures are followed
Increase in product quality	Cross-departmental shared knowledge and experience

3. Heijunka

Heijunka is a traditional scheduling methodology for multi-product environments, where production is 'levelled' by strategically alternating product mix to be manufactured in a given period. Establishing the size of production runs on the heijunka 'wheel' is often done periodically due to the complication of calculating the ideal run size for each wheel turn. A form of production scheduling that purposely manufactures in much smaller batches by sequencing (mixing) product variants within the same process that can help reduce lead times (since each product or variant is manufactured more frequently) and inventory (since batches are smaller).

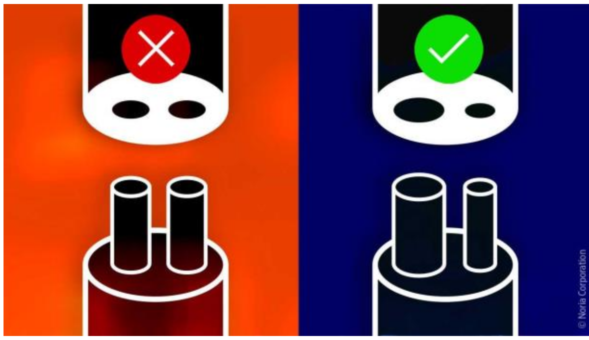
4. 3P (Production, preparation, process)

The Production Preparation Process (3P) is an effective method for examining the design and production of a product in its entirety. It takes teams through the creative process

of creating ideas and then narrows down the options to a single implementation-ready concept. Either the process or the product design can be the emphasis of a 3P project. The objective is to finish the event, which often lasts a week, with a solid understanding of how the technique should appear and how it will be constructed.

5. Poka-yoke (Error Proofing)

Poka-yoke is a common process analysis tool used in prevention-based industrial management that focuses on ensuring the appropriate conditions exist before to implementing any procedure. Poka-yoke decreases the likelihood of faults, rework, and human mistake by including automation, alarming, and labelling into the system's design.



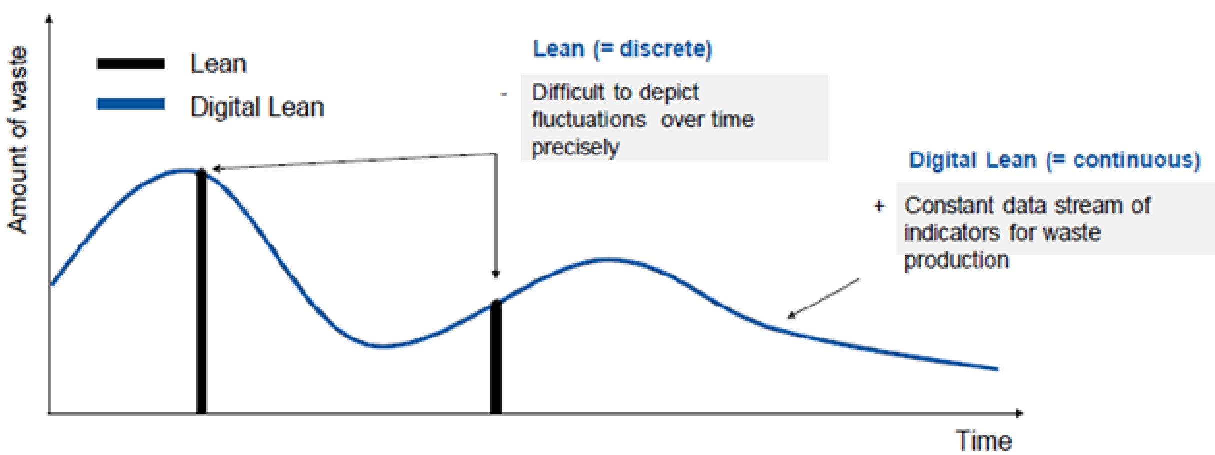
6. Just-in-time

Just-in-time manufacturing is the lean concept to reduce inventory waste, which is an on-demand system that allows manufacturers to go into production only after the customer has requested a product. This means that companies do not need to stock up on unnecessary inventory, lowering the risk of some components or products being overstocked or damaged while being stored. For example, during covid-19, we encountered overstock due to the stop of freight and shipment.

Definition of Digital Lean

What is Digital lean?

Digital lean is a powerful application which combines lean principles and Industry 4.0 technologies. With Industry 4.0 technologies and other digital tools, digital lean can provide more accurate, sophisticated, and real-time information about operations which helps understand lean principles and increases the impact of lean tools. Moreover, with growing processing power, high-frequency data from Industry 4.0 technologies is rising, making analytics and insight virtually possible in the future.



Digital lean is based on the traditional lean approach supplemented with capabilities of Industry 4.0 technologies. Digital lean uses continuous sensor data to track the amount of waste at any time and thus enables a more precise analysis of the waste production during a process. Compared to the traditional, digital lean can reduce more waste and accelerate waste identification and mitigation faster than traditional lean methods. Moreover, digital lean can discover information asymmetry and latency, which are the hidden components that affect the efficiency and output, resulting in high support cost and tangible bottom-line impact. The below list shows how traditional lean and digital lean mitigate the seven types of waste.

How digital lean can improve on traditional lean waste reduction

Waste Types	**Traditional Lean Identification and Mitigation**	**Digital Lean Improvement on Traditional Lean**
Overproduction	Mitigates the overproduction caused by the synchronisation between demand and supply, including	Provide real-time visibility into the value stream to proactively adjust capacity, avoiding the building

	delayed demand signals and rigid processes constraints	of goods that are not required.
Inventory	Instability across the value stream is often absorbed in additional inventory. Lean methods allow products to be manufactured only in quantity needed and at the time required.	Enhance operations with real-time visibility of the work-in-process inventory to identify unexpected inventory build-up throughout the production process.
Defects	Poor product design and process control increase defects across the value steam, causing rework or scrap. Reduce defects by establishing standards in the way assets are maintained, processes are defined,	Digital lean help identifies the precise asset, process step, or product feature causing defects and reducing first-pass yield.

	and products are designed.	
Over-processing	Traditional lean can help avoid processing not required by the customer that is performed across the value stream, such as over-inspection or unnecessary high tolerances.	Digital lean connects and integrates the life cycle (and the value stream) through a digital twin: a continuous thread of data mirrors development, production, and use that stretches from the initial design through the product's lifetime.
Waiting time	Unbalanced operations, bottlenecks, downtime, and poor production planning increase the waiting time along the	Digital lean reduces waiting through dynamic rerouting operations based on updates on the real-

	process, where employees, materials, and assets are not adding value. Traditional lean approaches help mitigate waiting time.	time status of assets, quick identification of bottlenecks, and multiple simulations of optimised scenarios.
Worker movement	Poor production lines and cell design increase operators' unnecessary motion to complete value-added tasks. Lean processes address these additional movements that do not add any value to the product and contribute to longer production times.	Digital lean, through analysing performance data or using augmented and virtual reality simulations, can better inform the design of layouts and equipment to optimise worker movement.
Transport	Reduces the nonlinear processes or processes scattered across the shop floor that require	Quantify the transportation time required per product or process, identifying

	transportation of materials from remote storage to the point of use.	opportunities to streamline and better organise the shop floor.

Table 1. How digital lean can improve on traditional lean waste reduction

There are three key enablers of digital lean: data collection, process standardisation and data enabling.

1. Collecting the data: IT and OT collaboration

Prior to the advent of Industry 4.0, information technology (IT) and operational technology (OT) were mostly separate fields with little crossover. To realise its full potential, digital lean necessitates the integration of IT and OT (control systems, industrial networks, etc.), which supplies plant and operation data to plant and business users.

2. Standardising processes: Process and data management

The data generated by plant processes acts as input for digital lean. However, if operations are not executed with standardisation and discipline, accurate and continuous data may not be produced. Thus, the effect of a digital lean project would be diminished. Important in this regard is the role of plant leadership in creating and enforcing practices that result in more precise data.

3. Enabling data through technology platforms

With the same importance as IT and OT collaboration and disciplined process and data management, relevant technological platforms should be chosen to optimise the benefits of digital lean. By considering the platform flexibility, integration with other systems and data administration, suitable technology platforms, such as digital twin, would be chosen by the organisations.

Analytics can have a significant impact on manual driven process manufacturing. Example technologies:

Machine-utilisation measurement

Photo-electronics sensor continuously tracks materials flow, running time, and idling to calculate overall equipment effectiveness.

Route track

The sensor analyses distance travelled and movement trajectory to calculate the output.

Motion measurement

The software automatically analyses the operator's non-value-adding activities via motion-detection sensors and an advanced computer-vision algorithm.

Cycle-time measurement

Radio-frequency identification records cycle times to find push-back incidents and calculate variance by the operator, shift, and line.

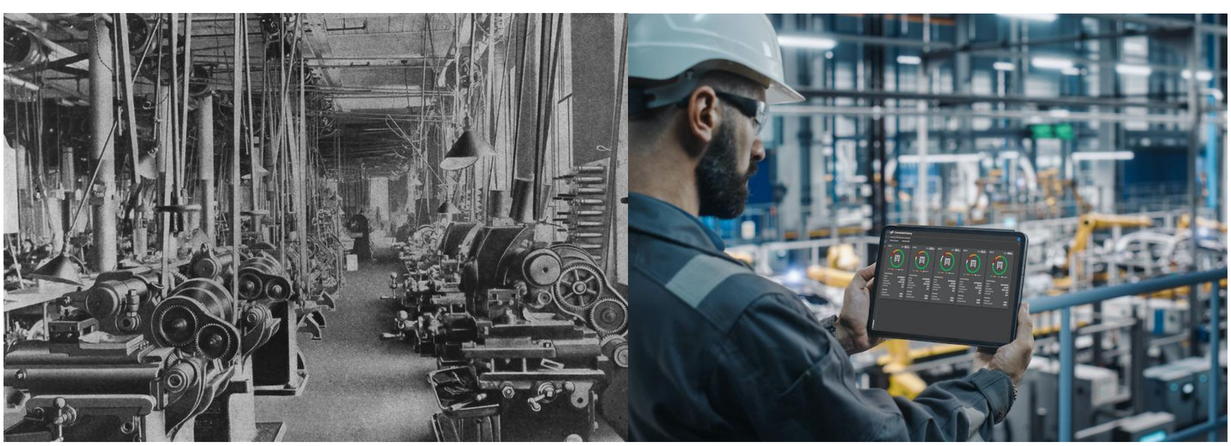
Digital performance management

Real-time data analysis and problem-solving for performance management

Traditional Lean and Digital Lean Comparison

The world is changing quicker than it has ever been before. As we reach the fourth industrial revolution, also known as Industry 4.0, which promotes the computerisation of production, firms are using digital technologies and transformations to increase the degree of digitalisation in the manufacturing industry. Manufacturers should go above and beyond to grasp and comprehend the tactical drivers of conventional and digital lean, which will help them maximise their lean tasks and activities.

When companies switch from conventional to digital lean, they must pay special attention to each lean tool's digitisation and understand how its implementation will value the existing method. Each classic lean tool has a specific purpose on the manufacturing work floor.



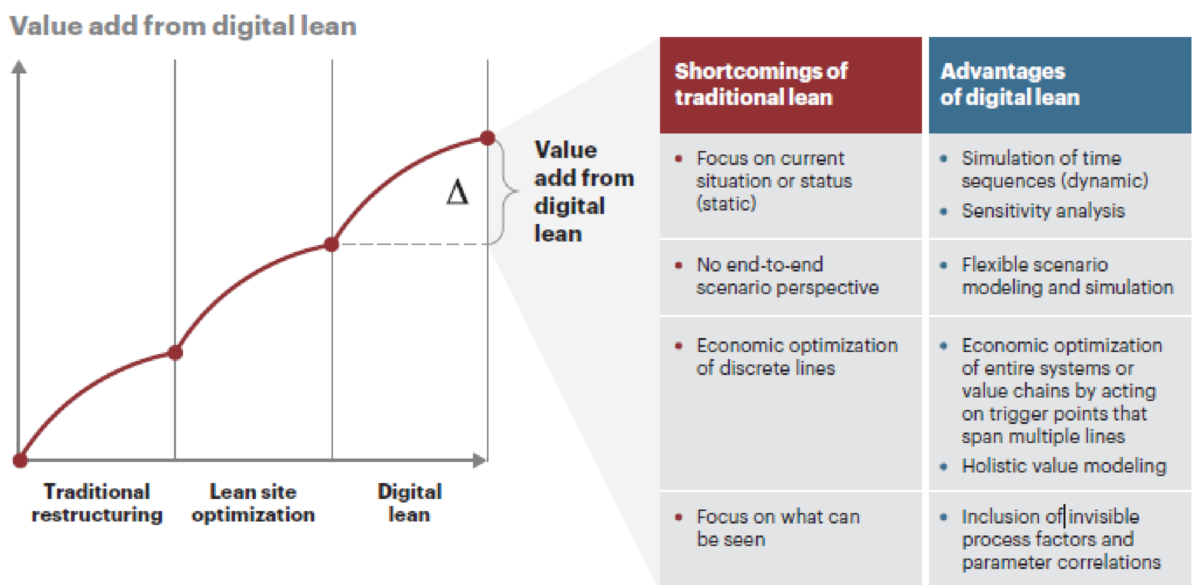
When combined with traditional lean techniques and tools, Industry 4.0's core enablers, such as sensor, network, data analytics, and human-machine interface, comprise the necessary transition to digitalise lean tools. The examples below illustrate how specific lean tools may be extended to digital lean.

Lean Tool	**Traditional Lean Examples**	**Digital Lean Examples**
Kanban	Record the consumption of part/ raw materials at the workstation and replenish it after reaching a certain level.	Auto-ID technology such as RFID sensors and digital twin to be applied to track the unit-level part/ material consumption.
Total Productive Maintenance (TPM)	TPM is typically performed periodically based on runtime, cycles, and other criteria to service equipment before a failure.	Advanced sensors and machine learning algorithms enable predictive maintenance. This allows extending maintenance intervals while simultaneously reducing failure events.

Heijunka	Establishing the size of production runs on the heijunka 'wheel' is often done periodically due to the complication of calculating the ideal run size for each wheel turn.	Advanced analytics can stabilise planning by using historical data from previous production runs to create optimised schedules based on machine availability, process quality, and resource requirements.
3P (Production, preparation, process)	As part of a 3P exercise, companies often construct cardboard or 2x4 mock-ups of future manufacturing lines, taking significant time and possibly creating waste.	Equipment connected to the industrial IoT and more advanced process and production data aggregation. Use the digital twin with data analytics to simulate the processes, troubleshoot the design, and optimise parameters.

Table 2. Lean Tools

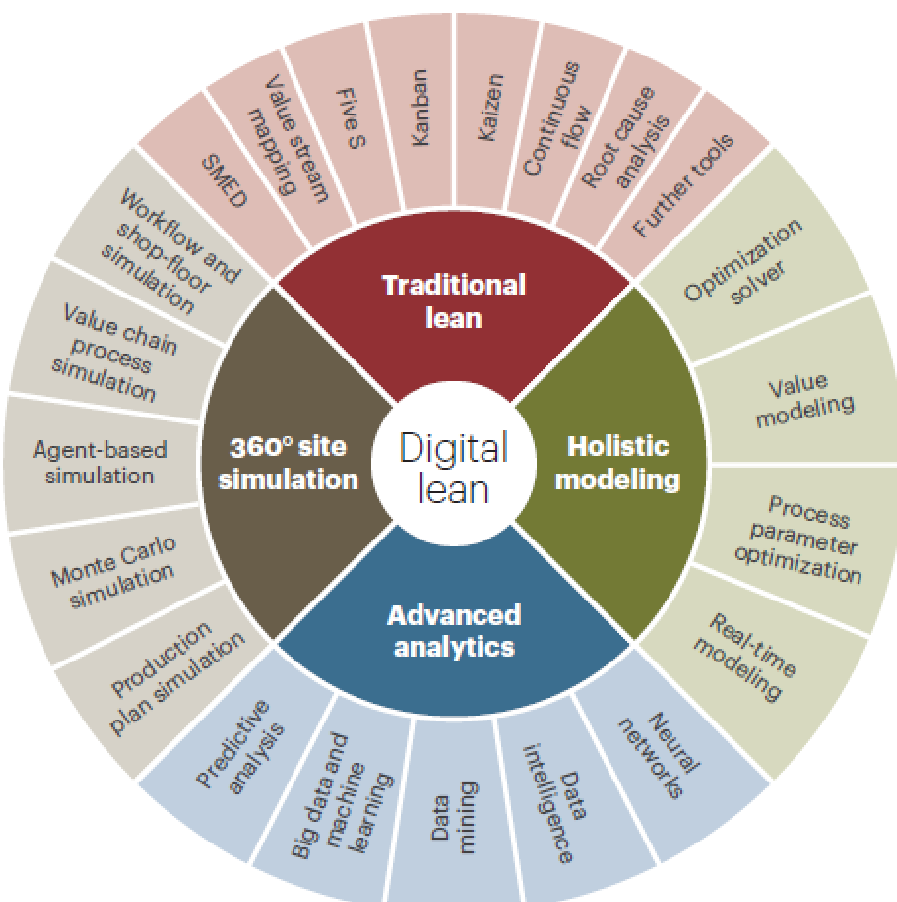
Digital lean is a powerful tool that blends lean concepts with Industry 4.0 technology to create a powerful application. Digital lean may deliver more accurate, complex, and real-time information on operations using Industry 4.0 technology and digital tools, which aids in understanding lean principles and boosts the effect of lean tools. The digital lean operates in other domains towards providing data-based approaches to decision making while emphasising the root causes of the business problems. Furthermore, as processing power improves, the availability of high-frequency data from Industry 4.0 technology grows, quickly making analytics and insight a reality.

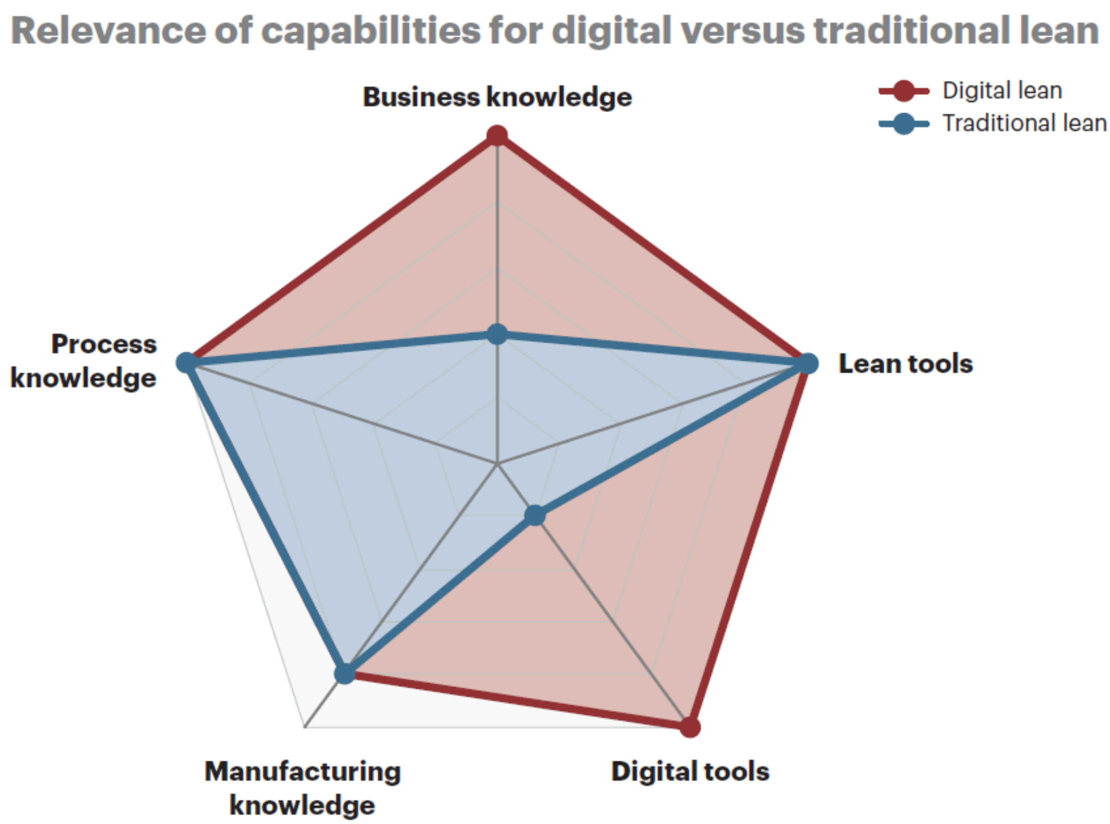


Traditional lean, a customer-driven continuous process improvement methodology, focuses on eliminating production inefficiencies, producing error-free procedures, and involving the entire production team. Single-minute die exchange, value stream mapping, 5S, Kanban, Kaizen, and root-cause analysis are all common lean tools.

Digital lean, on the other hand, focuses on optimising the overall manufacturing setup, such as through modifying work flows and challenging the order of process processes. Digital lean provides solutions to the following questions:

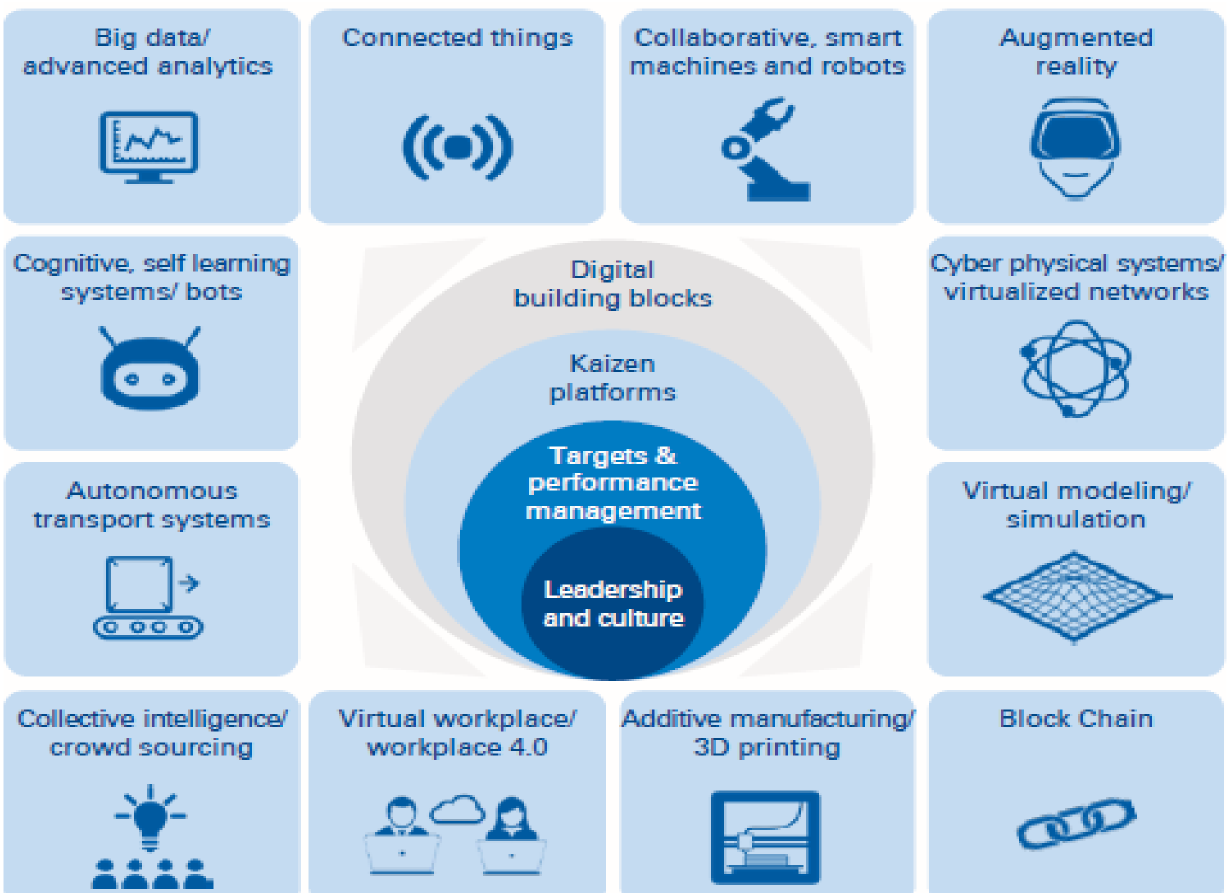
- How can material flows be optimised at each stage of the value chain?
- What additional savings can be produced by modifying the value chain, such as by combining or separating steps?
- How can manufacturing system robustness be improved? Where are the highest rates of failure? How may probable failure dependencies be addressed?





Digital lean holds great promise for manufacturers who are attempting to squeeze every last drop of efficiency out of a lean, yet highly interconnected, manufacturing value chain. But the promised benefits of digital lean will not be free (see above figure). Operations teams already possess the necessary tools for conventional shop-floor optimisation: process expertise, manufacturing knowledge, and mastery of conventional lean techniques. To obtain the digital lean incentive, chief operating officers will need to make substantial investments in the following crucial new areas:

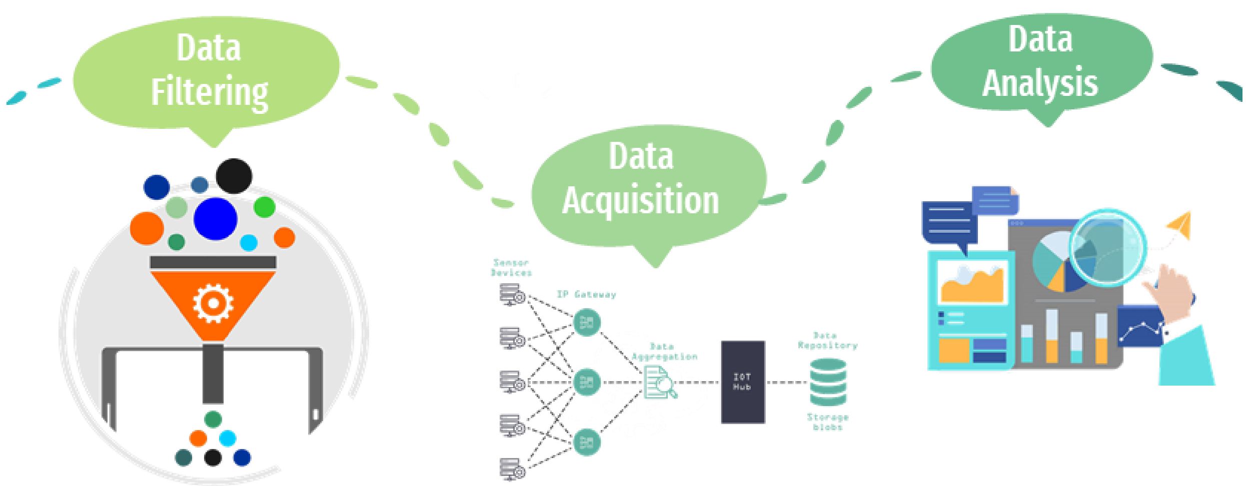
- Business knowledge, including the hiring of digital natives for operational excellence sectors with adequate understanding to effectively model financial, material, and information flows
- Digital tools, including not only the tools themselves but also the skills necessary to use them and understand (and apply) their output effectively
- Data security, adopting and implementing solid cyber defence plans to protect the enterprise from significant competitive and operational hazards The next stage on the path to the digital operations frontier is digital lean. Now is the moment to begin investing.

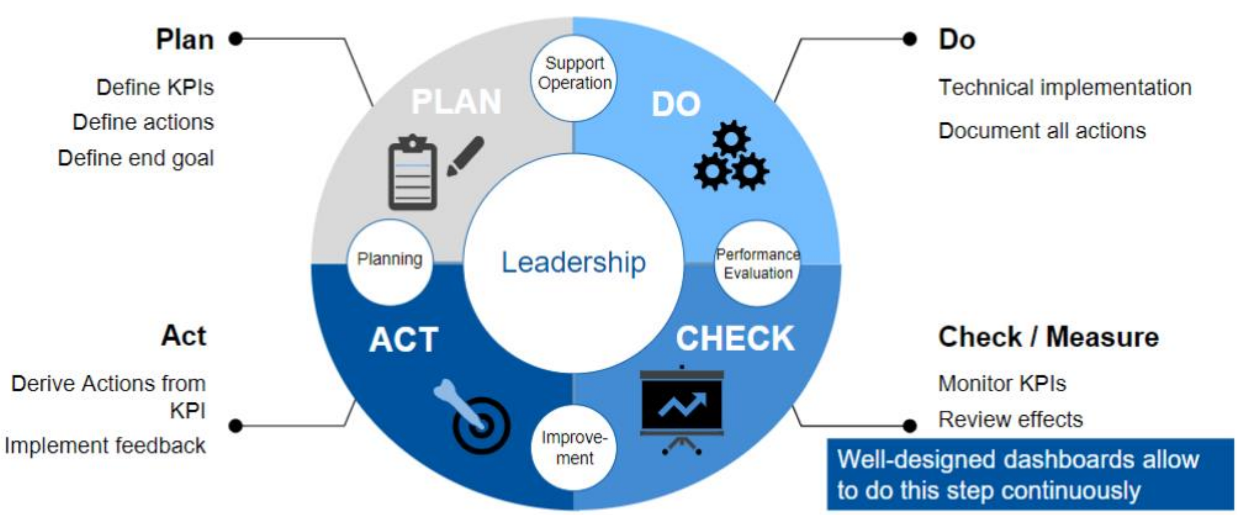


Compared to traditional, digital lean can reduce more waste and speed up the process of waste identification through fast data acquisition and direct detailed information collection. Moreover, digital lean can find out the asymmetry and latency of information, which are the hidden components affecting the efficiency and output, resulting in high supporting cost and tangible bottom-line impact. Based on the industry experience, most manufacturing enterprises lack real-time data on the state of equipment performance. On the contrary, there is also rare on the manual operation production line for real-time performance. It is common to rely on manual data recording in most current situations, which is not real-time and inaccurate to a certain extent.

Digital Lean Model, Methodology and Practices

The below diagram shows the methodology model of Digital Lean. In the first step, useless data will be filtered by lean management. Only relevant data, such as processing time, defeat rate, defeat reason, idling time, response time, output rate and downtime etc., will be collected by sensors (for example, optical sensors, weighing sensors or pressure sensors). After data acquisition, data will be displayed on the dashboard for monitoring and analysis.





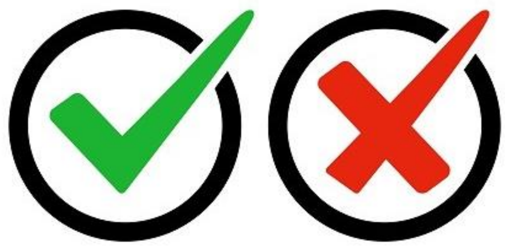
The PDCA (Plan-Do-Check-Act) is a tool for continuous improvement and iterative kaizen. It can be improved through continuous measurement by dashboards, if the right KPI are chosen. Also, it is an iterative, four-stage approach for continually improving processes, products or services and resolving problems. The PDCA Cycle provides a simple and effective method for solving problems and managing change. It enables businesses to develop hypotheses about what needs to change, test them in a continuous feedback loop, and gain valuable learning and knowledge. It promotes process optimisation on a small scale before updating company-wide procedures and work methods.

The PDCA cycle consists of four components:

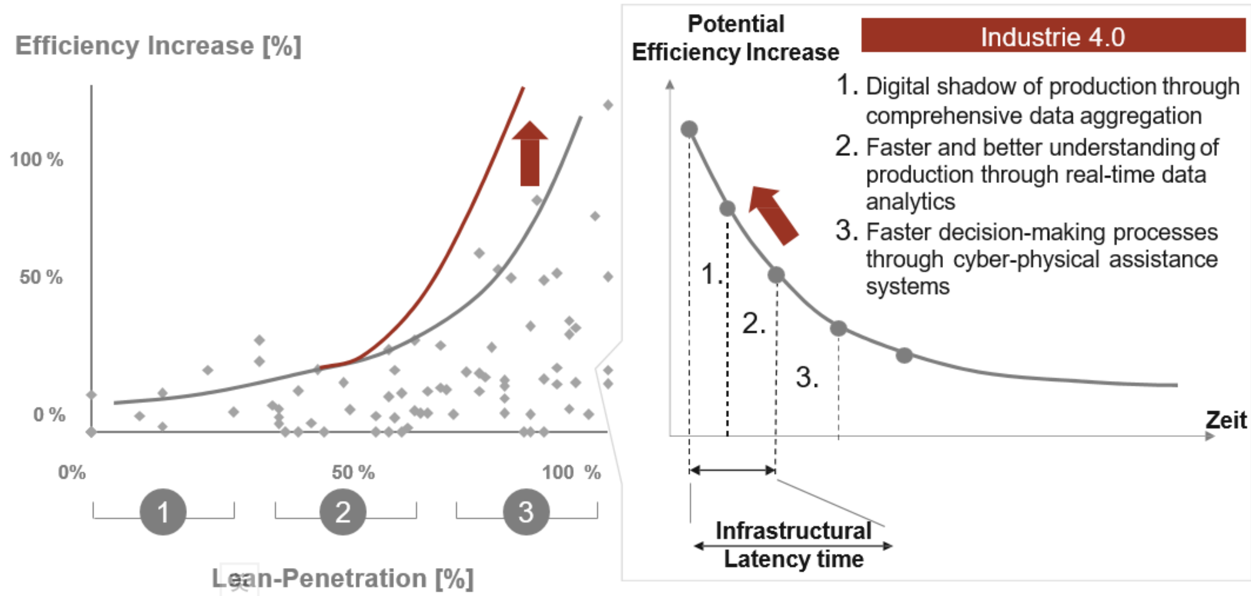
Plan–Identify the problem, collect relevant data, understand the problem's root cause, develop hypotheses about the issues, and decide which one to test.

Do–Develop and implement a solution; adopt appropriate lean tools (as shown in the diagram) to gauge its effectiveness, test the potential solution, and measure the results.

Check–Confirm the results through before-and-after data comparison. Study the result, measure effectiveness, and decide whether the process optimisation is supported or not.



Act–Document the results, inform others about process changes and make recommendations for the future PDCA cycles. If the solution was successful, implement it. If not, tackle the next problem and repeat the PDCA cycle.



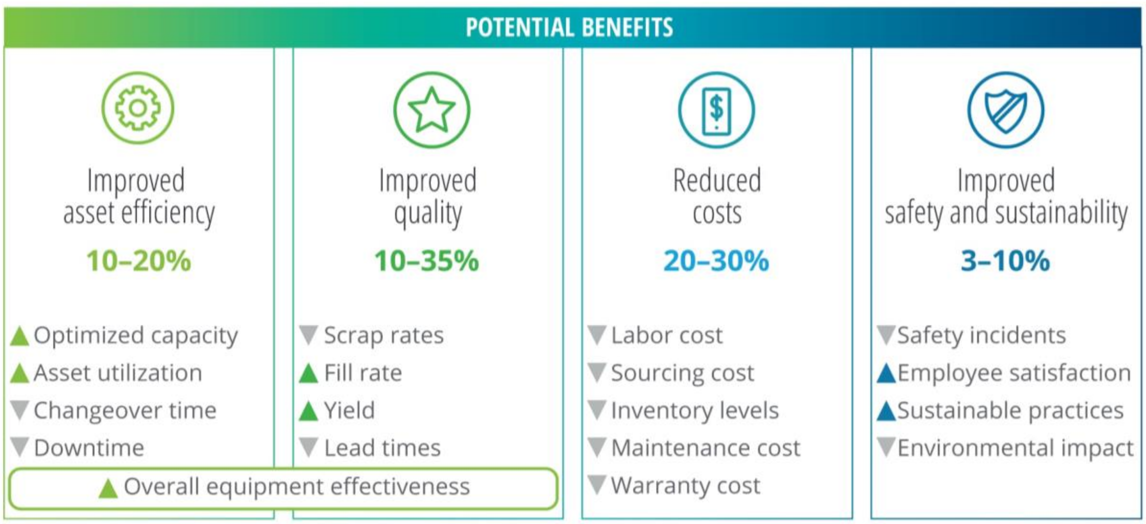
Source: WZL Benchmarking-Studie „Production Systems / i.A.a: zur Mühlen et al. (2009) Business Process Analytics (*Figure 2: digital lean*)

In this case, if the company would like to improve the operation for higher efficiency and productivity, due to the slow response of data, the improvement result would not be able to catch up with the rapid change in the market. As usual in production, the data is manually recorded, leading to a data availability latency—the latency of data delays the data analysis, decision making, and implementation. The whole improvement operation will be delayed, and the efficiency will be affected, which will lead to a slow response to the rapid change market. On the contrary, Digital lean enables data transparency through real-time data acquisition, leading to faster data availability and shorter decision-making latency. Therefore, real-time data availability and transparency could improve lean effectiveness. (Figure 2)

Enterprise Benefits of Digital Lean Adoption

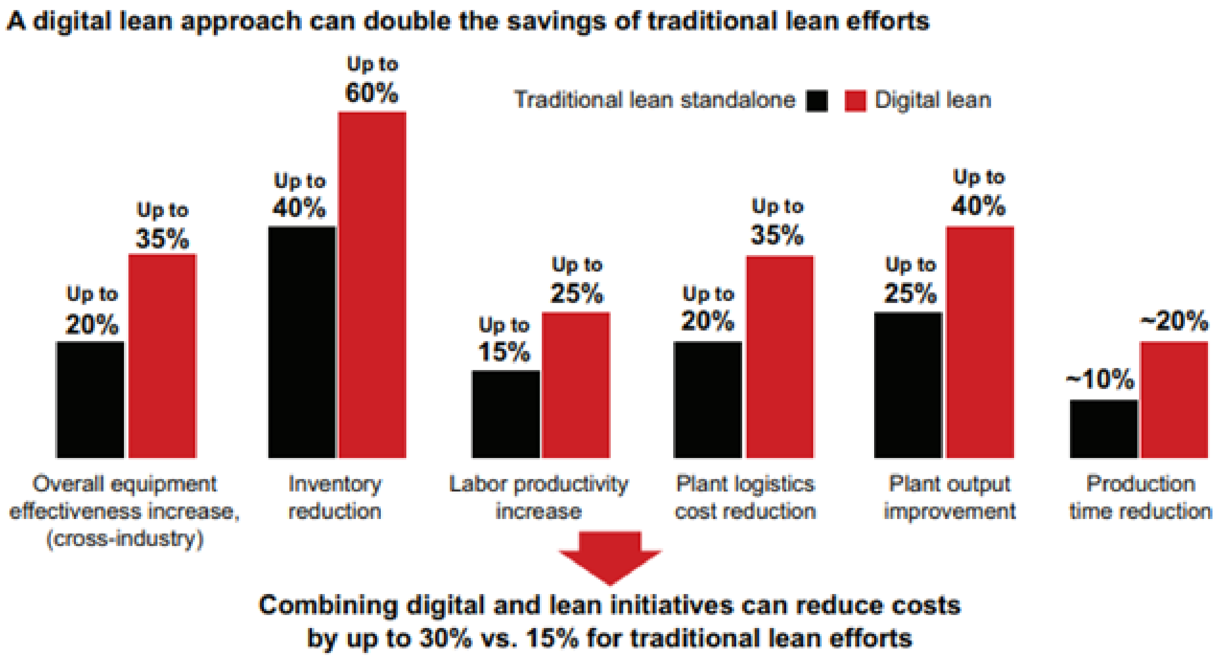
According to an article in "The Age of Analytics: Competing in a Data-Driven World" (2016), "big data does not only give managers a real-time view of the "life" of the plant (production, processes, and equipment), but also opens up new opportunities in asset management, end-to-end supply chain visibility and planning, and many other aspects of manufacturing.". It is imperative to enhance proficiency and accuracy in advanced data modelling and analytics to develop a response to competitive pressures and master the complexity of the manufacturing process. Companies will increase productivity and address individual products with lower complexity costs by applying digital lean technology in smart production and smart networks. Digital lean is expected to help enterprises reduce costs and improve quality. The availability of up-to-date and high-quality data enhances transparency and facilitates the identification of waste.

Through digitalisation, it is allowed a higher degree of flexibility on product customisation. Manufacturing may employ digital lean to expand on its lean foundation while using new technologies like machine learning and predictive maintenance to solve previously unsolvable business difficulties and unlock previously unreachable projects.



The ranges in above figure represent the percentages of available opportunity, which are influenced by a number of elements that should be assessed throughout the construction of the business case. Manufacturers should concentrate digital lean initiatives and programmes on the largest areas of potential for the highest ROI. In general, these include releasing the capacity of limited assets, enhancing the efficiency of strategic assets, reducing the relatively high total costs of low quality, reducing labour expenditures, and reducing or eliminating needless raw material expenses.

According to the study "Digital Tools Can Double Lean Six Sigma Savings" (2019), when comparing the implementation of "Digital Lean" to "Traditional Lean", it can increase labour productivity by up to 20%, output improvement by up to 40%, and reduce production time by up to 20%.



Improvement of equipment effectiveness due to higher planning quality, forecasting capability, and agile company processes. Inventory cost reduction is due to a decrease in inventory level through real-time information collected by digital lean tools such as different sensors over the whole supply chain and production. Labour productivity improvement is realised by leveraging the flexibility of labour in production and a higher degree of automation. Machine and digital technology also replace the labour force. Due to better automation and material flow harmonisation, logistics cost reduction is also achieved over the whole supply chain. Quality cost reduction due to the availability of real-time data to optimise quality issues and help find out the cause and solve it quickly—faster value generation due to agile organisation and collaboration and steering the value chain based on data transparency.

It is anticipated that digital lean will assist businesses in cutting expenses while also raising quality. Through the implementation of digital lean technology in smart production and smart networks, businesses will be able to achieve higher levels of productivity and cater to a greater variety of specific products at reduced levels of complexity expense.

Increase in equipment effectiveness (15% increased)

Increase in the effectiveness of the equipment as a result of improved planning quality, increased capacity for forecasting, and more agile organisational operations.

Reduction in inventory cost (20% reduced)

Reduced inventory costs as a result of a lower minimum inventory level achieved through the use of real-time information gathered by digital lean tools such as a variety of sensors distributed across the production and supply chain. This resulted in a cost savings.

Increase in labour productivity (10% increased)

Labour productivity can be increased by using labour flexibility in production and a higher level of automation. Labour is also being replaced by machines and digital technology.

Reduction in logistics costs (15% reduced)

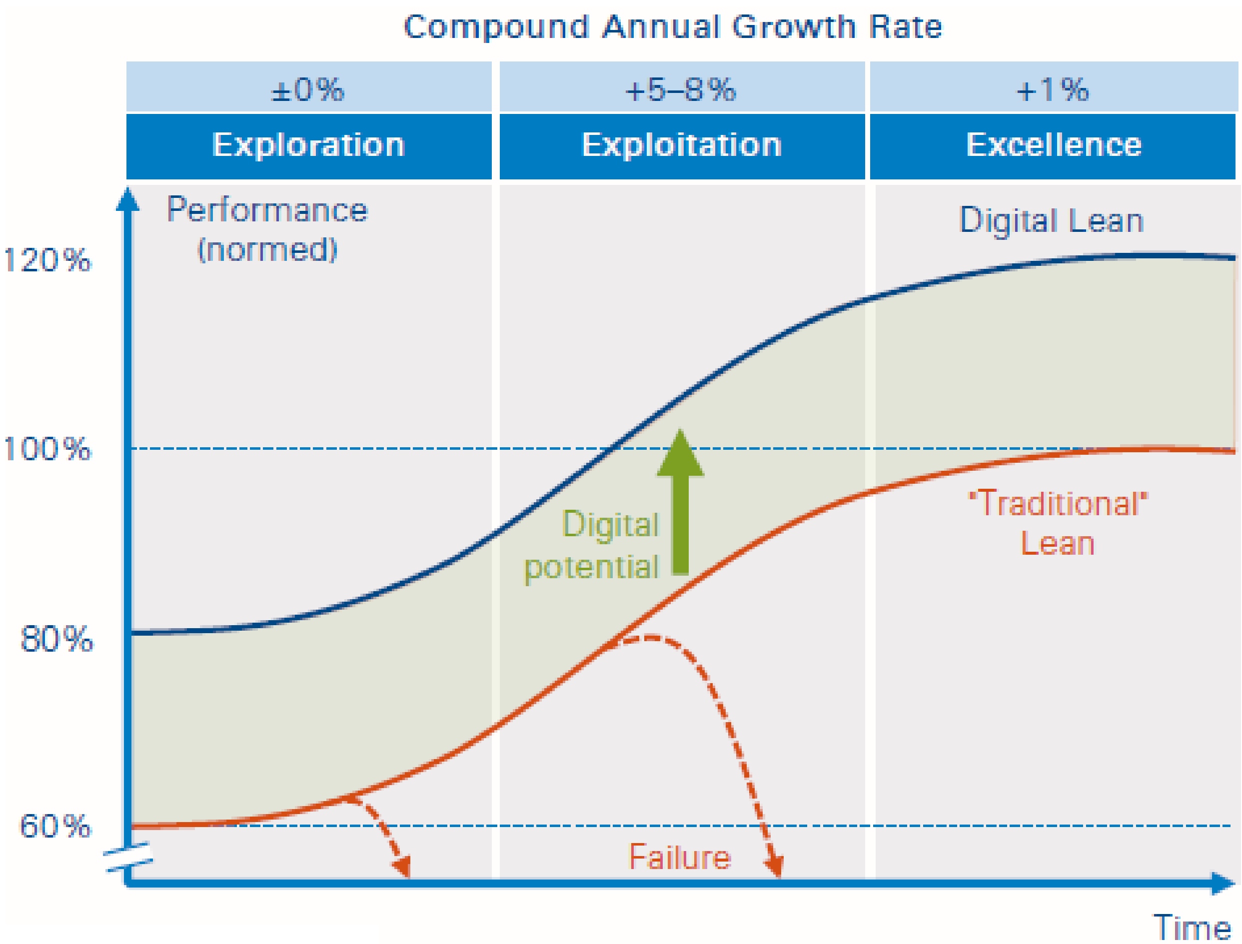
The entire supply chain will experience a reduction in logistics costs as a result of improved automation and more streamlined material flow.

Increase in plant output (15% increased)

A reduction in the cost of quality as a result of the availability of data in real time to optimise quality problems, assist in determining their cause, and expedite their resolution.

Reduction in production time (10% reduced)

A quicker generation of value as a result of an agile organisation and increased levels of collaboration, as well as the ability to drive the value chain based on the transparency of data.



According to an analysis from Boston Consulting Group (BCG), there are four benefits of integrating digital lean and Industry 4.0 solutions to address pain points.

Changeover Efficiency Facilitation

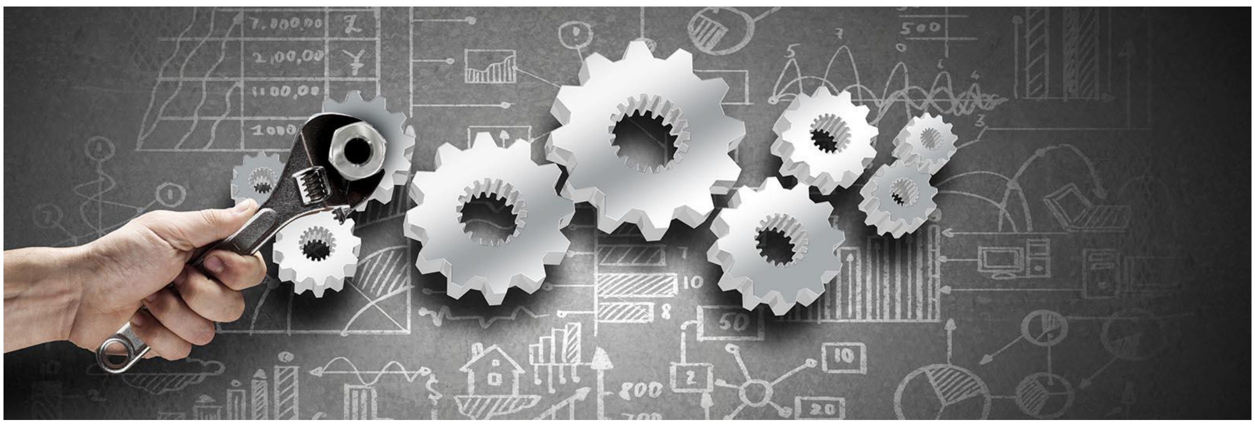
One of the manufacturer's objectives is to have a flexible operation that permits the production of multiple goods on a single production line.

However, it is difficult to realise the benefits of flexibility due to the time-consuming adjustments required to prepare machinery to make diverse items. By applying lean technologies like as the one-minute exchange of dies, manufacturers can eliminate non-value-adding operations during the changeover, thereby expediting the process dramatically. The technologies of Industry 4.0 complement these efforts. New sensors and software enable machines to detect products autonomously and load the relevant program and tools without human interaction. Because the switchover is automated, operators may concentrate on value-adding tasks.

A manufacturing, for instance, created a tracking system that classifies and manages each product using radio frequency identification tags attached to individual work pieces. The system is utilised by assembly stations to identify the next product to be manufactured and configure the appropriate tool parameters. Without operator intervention, the production line can be instantaneously reconfigured.

Productivity Enhancement Through Predictive Algorithms

Equipment failures and breakdowns are a common cause of decreased production and increased inventory levels across many different manufacturing sectors. Companies have the ability to increase the overall effectiveness of their equipment by utilising lean approaches such as autonomous or preventative maintenance (OEE). For instance, businesses often delegate particular do-it-yourself maintenance tasks to their employees in order to facilitate the usage of autonomous maintenance. This helps to drastically cut down on the amount of downtime required to address comparatively small problems. Leading factories are maximising the benefits of these lean processes by analysing the massive amounts of data acquired by sensors through the application of cutting-edge analytics algorithms and machine learning strategies. The result indicates any possibility for breakdowns to occur before they really take place. These kinds of predictive insights equip operators to carry out autonomous maintenance at the optimum moment, hence avoiding disruptions and minimising unnecessary downtime and expenses associated with replacements.



For example, an aluminium manufacturer employs mobile devices to deliver real-time information on equipment performance to its maintenance teams, indicating where problems are occurring or likely to occur, as well as the underlying causes. The devices are also used by the teams to obtain maintenance information (such as machine blueprints) and to receive remote guidance on the tools needed to perform repairs.

Real-time Data Acquisition in Production Management

Data collected in real time can help improve and speed up attempts to achieve continuous improvement. Line employees and managers can use real-time data to determine the underlying causes of performance problems and accelerate the validation of improvement initiatives, which will allow for a speedier rollout throughout the plant.

Real-time monitoring is something that businesses can utilise every day to cut down on their reaction and response times. For instance, a provider of C-parts (such as, for example, screws, nuts, and washers) has attached camera systems to the containers that hold the components inside the warehouses and production lines of its customers. When the inventory falls below a predefined minimum, the systems initiate the automatic replenishment of parts, and the manufacturer reaps the benefits of just-in-time refilling.

Quality Control in Self-Inspection

When products fail to satisfy criteria, production capacity is lost and cannot be recovered. Even worse, if a manufacturer provides products to consumers that are of low quality, the customers will have to pay more money overall and are likely to lose trust in the supplier. A large number of lean management tools, such as self-inspection, poka-yoke, and jidoka, have been developed in order to raise the rate of error detection as well as the rate at which faults are discovered. However, in order to reach the goal of zero defects, manufacturers are required to provide assistance for self-inspections and employ a data-driven analytics strategy in order to determine the underlying causes of errors. These kinds of supports are made possible by the technologies of Industry 4.0, which provide dependable context data and the capacity to carry out extensive tracking. Improvements can be made to error analysis by utilising techniques like as camera-based visual inspection, correlation models, and real-time monitoring of process parameters, amongst other things. The operators of the production process are able to ensure that the end product conforms to high-quality standards by performing real-time analyses of the data collected by the inspection system.

Section 2: Digital Lean Guidance and Roadmap

Introduction of "Digital Lean Analyser" And POC of Digital Lean

In the manual operation assembly line, many problems could be found generally and the corresponding lean tool with collecting data of key factors usually addresses those problems. Before to develop a tool kit, it should identify the problems in manufacturing industry. Below list has shown the problems, lean tools and corresponding key factor.

	Problem	**Lean Tool**	**Key factor**
Inspection	Manual Recording	Automation	No. of Defect
	Too many inspection stations	Quality At Source	Defect type
	Misjudge	Automation	
Manual Assembly	Line unbalance	Line Balancing	Processing time
	Too many WIP	WIP Reduction	Idle time
	Bottleneck	Bottleneck Removal/ Line Balancing/	Waiting time

		Takt Time analysis	
	Chance to overproduction	Waste Elimination	Response time
	Product loss	Visual Management	Labour efficiency
	Labour efficiency	Overall Operator Efficiency	Productivity
	Manual Recording	Automation	Output rate
	Machine Maintenance Problem	Maintenance Optimisation	Machine down time

To deal with the problem, a digital lean tool kit is developed. It is involved hardware and software development. With the aid of an experimental tool kit, real-time data can be collected by an integrated solution tool kit. The tool kit will consist of sensors, Human-machine Interface (HMI) and a digital dashboard for data projection.

The tool kit is granted with an HK short-term patent (HK30025487) and a PRC utility patent (publication number:212433628U).

证书号第12404069号

实用新型专利证书

实用新型名称：生产线精益分析装置

发 明 人：黎永晶;陈倩莹

专 利 号：ZL 2020 2 1730570.3

专利申请日：2020 年 08 月 18 日

专 利 权 人：香港生产力促进局

地 址：中国香港九龙

授权公告日：2021 年 01 月 29 日 授权公告号：CN 212433628 U

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2021 年 01 月 29 日

第 1 页 (共 2 页)

知識產權署專利註冊處
Patents Registry
Intellectual Property Department

香港特別行政區政府
The Government of the Hong Kong Special Administrative Region

批予短期專利證明書

《專利條例》(第 514 章)

CERTIFICATE OF GRANT OF SHORT-TERM PATENT

Patents Ordinance (Chapter 514)

茲證明下述短期專利在今日批予:
I hereby certify that a short-term patent with the following particulars has been granted today:

專利編號 Patent No.: HK30025487 **申請編號** Application No.: 32020014192.9

專利所有人姓名或名稱及地址 Name and Address of Proprietor:
香港生产力促进局
Hong Kong Productivity Council
香港
九龙达之路 78 号
生产力大楼

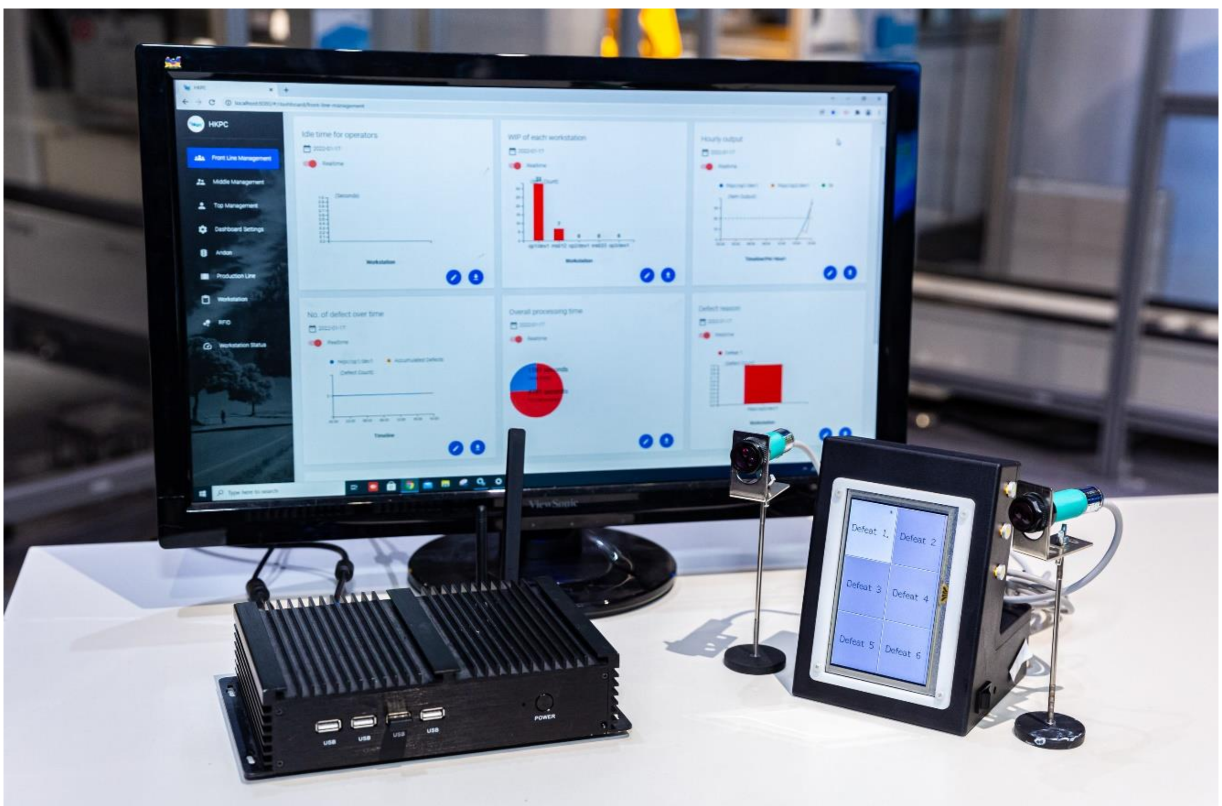
發明名稱 Title of Invention:
生產線精益分析裝置及方法
DEVICE AND METHOD FOR PRODUCTION LINE LEANNESS ANALYSIS

短期專利有效期 (在符合續期的規定下) Term of Short-term Patent (subject to renewal):
由 18.08.2020 起計 8 年
Eight years commencing on 18.08.2020

Moreover, it is granted "Geneva International Invention Exhibition 2022" Bronze Award.

This invention only requires short lead-time to set up, which can cope with tight production schedules. The technique of this Analyser is easy to master. Combining digital and lean initiatives can reduce manufacturing costs by up to 30%, comparing with only 15% for traditional lean efforts. With the application of real-time data technology, this invention helps manual driven process industries to reduce waste, improve production efficiency and identify the bottlenecks in the production line. By applying Digital Lean, the production process can be streamlined with real-time data analysis and visualisation. Productivity and efficiency of production lines can also be improved, thus increasing revenue.

In this invention device, data will be collected by infrared diffuse reflection photoelectric switch sensor and the soft key button through the digital lean analyser device. Through the software, data such as processing time, waiting time and WIP will be visualised in graph or chat and displayed on the screen.



Tool Kit - Digital Lean Analyser

The visualisation level will divide into 3 levels for different users.

– Front Line management (i.e. Line leader)

Data Type	**Display Chart**	**Remarks**
Processing time of each workstation	Line chart	• To compare the takt time and find out the bottleneck
WIP of each workstation	Line chart	• To compare the limited WIP
Hourly output	Bar Chart	• To monitor the hourly output and target output
Overall processing time	Pie Chart	• Display the VA and non-VA time percentage
No. of defect over time	Line Chart	• To alert the defect rate when it rising in short
Defect reason	Bar chart	• Distribution of defect

Idle time for operators	Bar chart	• Waiting time and repairing time of machine repairing for each case

– Middle management (i.e. Production Supervisor)

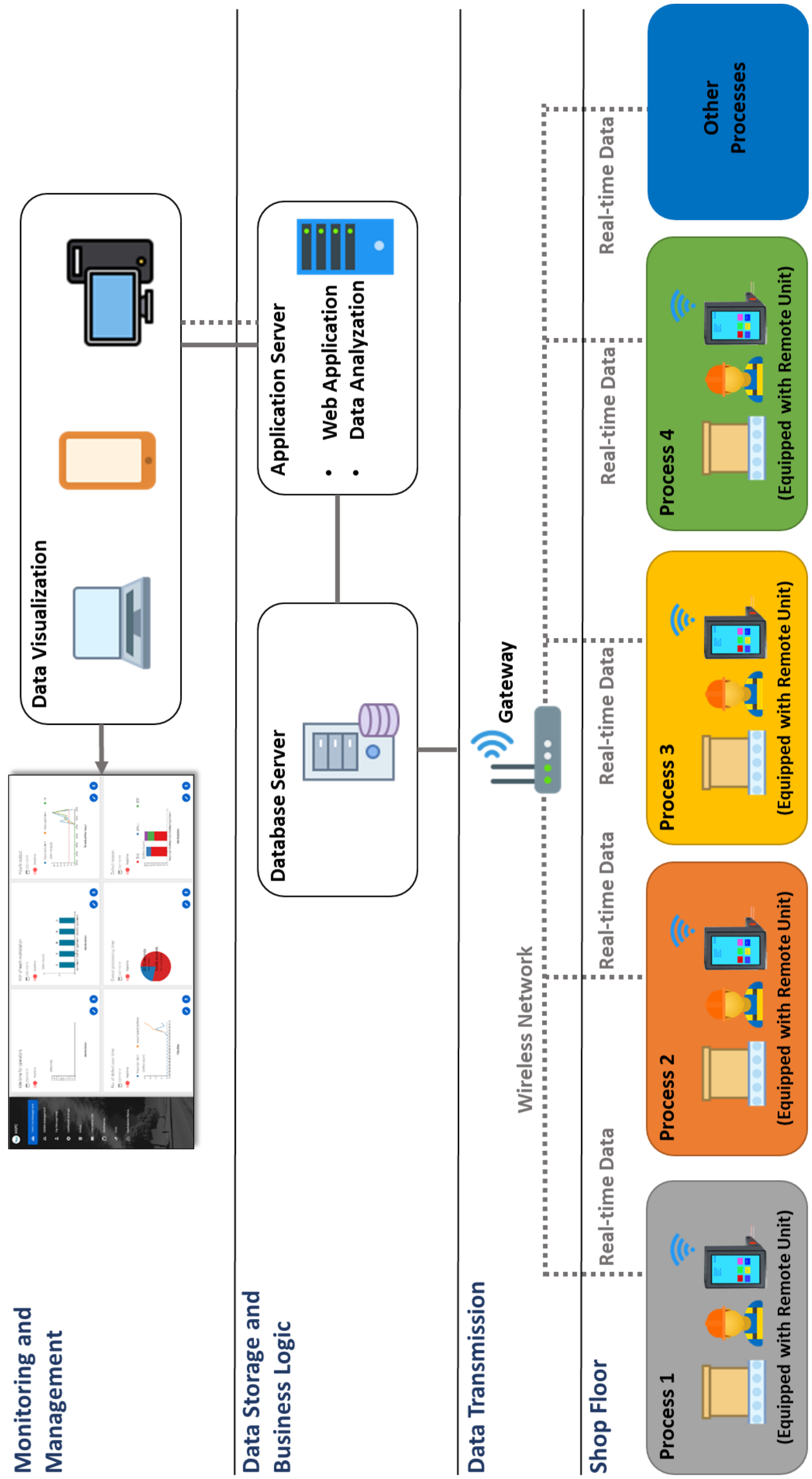
Data Type	**Display Chart**	**Remarks**
Processing time of each workstation per production line	Line chart	• To compare the takt time and find out the bottleneck
Production situation per production line	Clustered 2-Column Chart	• Compare the planned production and real time situation
Daily output over period per production line	Line chart	• To monitor the daily output and target
Overall processing time per production line	Pie Chart	• Display the VA and NVA time percentage
Defect rate per hour	Line Chart	• To monitor the quality stability

Idle time for each mechanic	Bar chart	• Evaluate their performance

– Top management (i.e. General Manager)

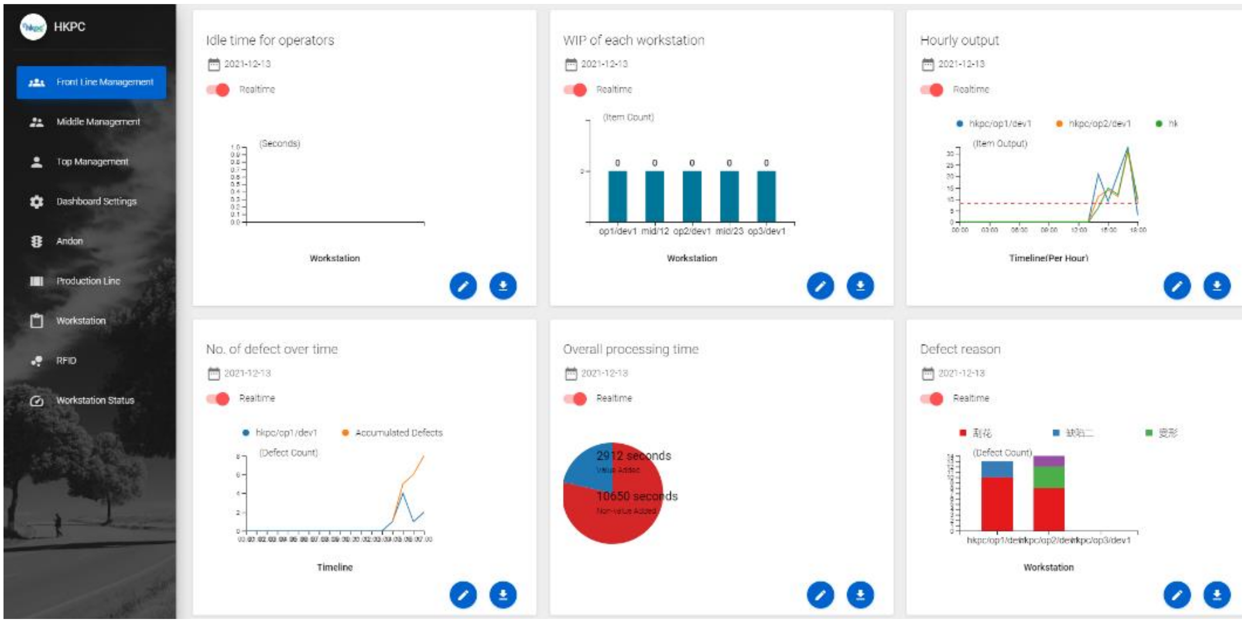
Data Type	**Display Chart**	**Remarks**
Processing time of each workstation	Line chart	• To compare the takt time • Highlight the workstation which is unbalanced
Production situation per production	Clustered 2-Column Chart	• Compare the planned production and real time situation
Overall processing time	Pie Chart	• Display the VA and non-VA time percentage
Average Idle time for each problem	Clustered Column Chart	

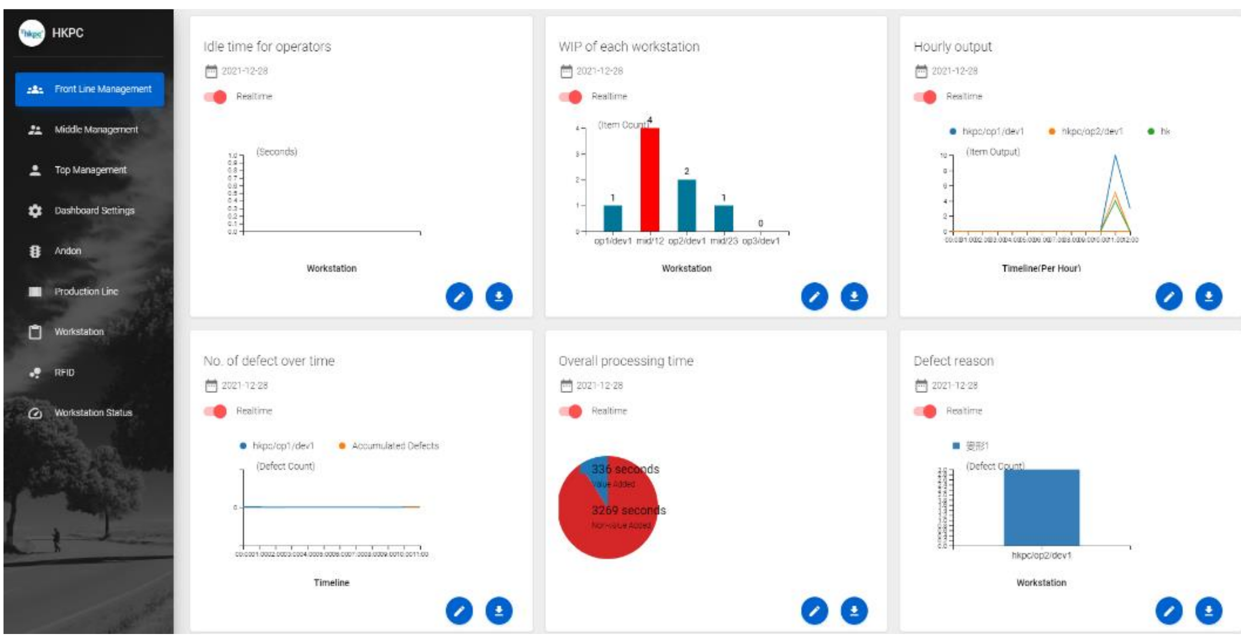
Topology and Schematic diagram



Estimated Production Performance in Digital Dashboard

The dashboard will be as below to show different production lines' productivity, operator efficiency, and quality problems in real-time.





Digital Dashboard of Digital Lean Analyser

Scenario Testing and Verification

There are three scenarios for the digital lean tool kits.

The below testing script is for the verification of functions in tool kits.

1. Testing Scenario of Processing Time Collection

	Input Parameter				Scenario Setting						
Scenario	**D**	**C (in sec)**	**C' (%)**	**WIP**	**S_1**	**S_2**	**S_3**	**S_a (S_2-S_1)**	**S_b (S_3-S_2)**	**Detective Zone**	**Expected Result**
1	40 cm	5	20	3	O is staying at S_1	-	-	-	-	0 - 30cm	Invalid Record
2	40 cm	5	20	3	O is traveling back and forth quickly	-	-	-	-	0 - 30cm	Invalid Record
3	40 cm	5	20	3	O Passed *10	O Passed*10	-	All are within 4 – 6 s	-	0 - 30cm	Normal
4	40 cm	5	20	3	O Passed *10	O Passed*10	-	2 of records are 2s	-	0 - 30cm	Normal
5	40 cm	5	20	3	O Passed *10	O Passed*10	-	2 of records are 7s	-	0 - 30cm	Normal but accumulate record
6	40 cm	5	20	3	O Passed *10	O Passed*10	-	3 of records are 7s	-	0 - 30cm	Abnormal
7	40 cm	5	20	3	O Passed *10	O Passed*7	-	All are within 4 – 6 s	-	0 - 30cm	3 invalid records and abnormal

8	40 cm	5	20	3	O Passed *10	O Passed*7	-	3 of records are 7s	-	0 - 30cm	Abnormal

Input Parameter:

D = Detectable distance

C = Standard processing time

C' = Allowance in percentage

S1, S2, S3, S4 =Sensor

Sa = Actual processing time in Station 1

Sb = Actual Waiting time

O = Object

Alert Rule:

1. Actual Processing time > Standard Processing time with allowance for 3 times (accumulate)
2. Waiting time > Standard Processing time with allowance for 3 times
3. Accumulate 3 or above invalid records
4. WIP > 3

2. Testing Scenario of Defect Key-In (For inspection process) Function

	Input Parameter			**Scenario Setting**				
Scenario	**F**	**C (in sec)**	**C' (%)**	**S_1**	**A**	**S_2**	**S_a (S_2-S_1)**	**Expected Result**
1	3	5	20	O Passed *10	-	O Passed*10	All are within 4 – 6 s	Normal and all pass goods
2	3	5	20	O Passed *10	2 input	O Passed*8	All are within 4 – 6 s	Normal and record 2 defects
3	3	5	20	O Passed *10	3 input	O Passed*7	All are within 4 – 6 s	Abnormal
4	3	5	20	O Passed *10	5 input	O Passed*5	All are within 4 – 6 s	Abnormal and alert when defects hit 3 times
5	3	5	20	O Passed *10	1 input	O Passed*10	All are within 4 – 6 s	1 invalid records and normal
6	3	5	20	O Passed *2	2 inputs	-	The time between 2 Input is too short	Invalid Record
7	3	5	20	O Passed*2	-	O Passed *5	All are within 4 – 6 s	3 invalid record and abnormal

Input Parameter:

F = allowance number of defects

C = Standard processing time

C' = Allowance in percentage

S1, S2 =Sensor

Sa = Actual processing time in Station 1

A = Remote Unit

O = Object

Alert Rule:

1. Actual Processing time > Standard Processing time with allowance for 3 times (accumulate)
2. Waiting time > Standard Processing time with allowance for 3 times
3. Accumulate 3 or above invalid records
4. Accumulate 3 or above defectives

3. Testing Scenario of Andon Function

	Input Parameter		Scenario Setting					
Scenario	**W in sec**	**R in sec**	A			t_a	t_b	**Expected Result**
			t_1	t_2	t_3	$t_2 - t_1$	$t_3 - t_2$	
1	5	10	Operator input once	C1 is read	C2 is read	within 5 sec	within 10 sec	Normal
2	5	10	Operator input twice	-	-	-	-	1 invalid record
3	5	10	Operator input once	C1 is read	-	7 sec	-	abnormal and accumulate record
4	5	10	Operator input once	C1 is read twice	-	within 5 sec	-	1 invalid record
5	5	10	Operator input once	C1 is read	C2 is read	within 5 sec	within 1 sec	t3 record is invalid
6	5	10	Operator input once	C1 is read	C2 is read twice	within 5 sec	within 10 sec	1 invalid record

Input Parameter:

W = allowance waiting time

R = Standard repairing time

A = Remote Unit

C1 = Mechanics card

C2 = Supervisor card

t1 = operator input time

t2 = mechanics arrival time

t3 = supervisor approval time

ta = actual waiting time

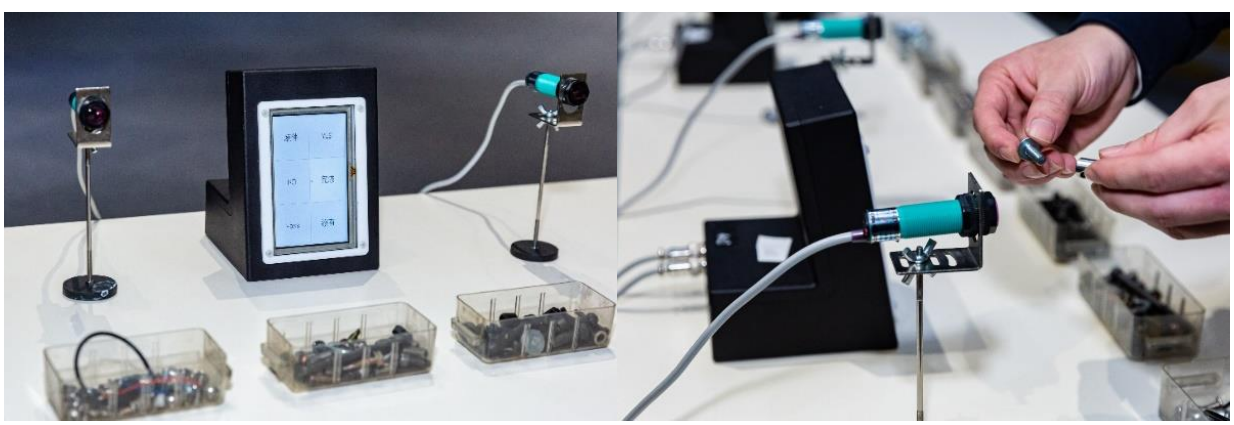
tb = actual repairing time

Alert Rule:

1. Waiting time > standard waiting time for 3 times
2. Accumulate 3 or above invalid records
3. C1 is read by other A while repairing

Its objective is:

- To have in-depth analysis of critical processes
- To enhance visual management and data transparency
- To evaluate operators' performance and line balancing performance
- To optimise the work force in the production line and sustain the process flow
- To predict and immediately alert emergency response team the potential risk or quality problems so as to take proactive preventive actions and enhance the resilience
- To identify the in-line problems and causes in real-time, able to take Kaizen initiative promptly



Case Studies and Solutions of 20 Pilot Companies

To assist Hong Kong manufacturing enterprises in building up the foundation of Industry 4.0 by implementation of Digital LEAN, Hong Kong Productivity Council (HKPC) have developed a digital lean analyser for real time monitoring and data collection and analysis in manual driven process to showcase and demonstrate the concept of digital lean and Industry 4.0 in 20 recruited pilot company. In these 20 pilot enterprises, a case study of utilising digital lean analyser for data collection and identifying bottlenecks in manual processes was conducted. They were recruited from many industries, including the toy, metal, home appliance, logistic, printing, electrical, and seal product industries, among others.
During the course of case studies, both the digital lean and Industry 4.0 concepts will be presented, and the level of digital lean and Industry 4.0 that each firm possesses will be studied and evaluated. The businesses will then be given suggestions for how they might improve, as well as direction regarding their transition into the Industry 4.0 era.

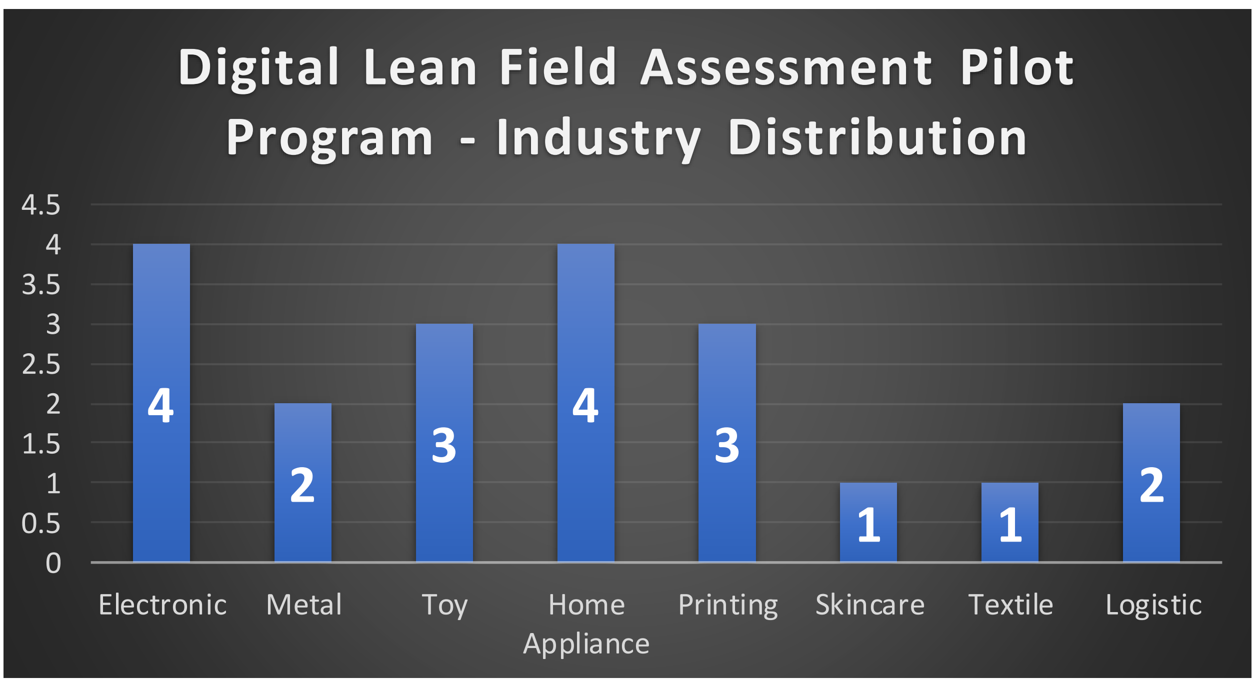
It is hoped that in this project, Hong Kong enterprises with scoping in manual driven process to:

- understand the form and direction of more solutions
- understand the effectiveness of practicing Digital Lean

- guide to self-assessment of enterprises in Hong Kong, select the appropriate solution
- strengthen their understanding of the foundation of Industry 4.0 and the importance of Digital Lean

Flow of onsite study:

1. Project Introduction
2. Briefing of Digital Lean and Industry 4.0 Concept
3. Interview of top management
4. Understand the company operation and work flow
5. Onsite inspection for workflow and process
6. Conclusion and advice to enterprise

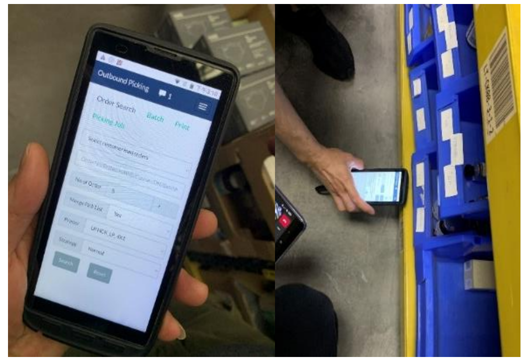


Manual Driven Process Highlight from 20 Pilot Companies

Case 1 (Logistic Industry)

1. <u>Receiving order by hand-held device</u>

- Using PDA and QR-code system for goods management

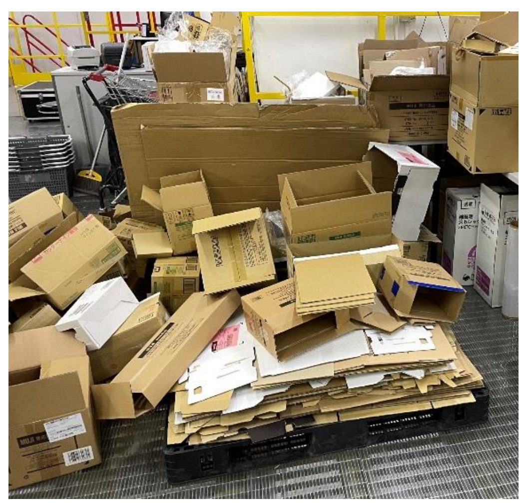


2. <u>Picking goods</u>

- Manual goods picking with bucket trolley, no route planning,

3. <u>Choosing Suitable Size Package Box</u>

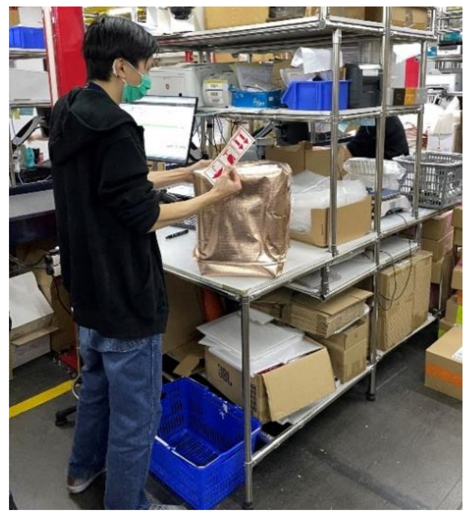
- Workers need to find a suitable size box for different ordered goods packaging.



4. Packaging

- Manual packing with tape
- Process time depends on the size the box

5. Labelling



- Input order data in computer
- Generate and print out the label with bar code
- Manual label sticking

The picking and packing procedures need manual operation and there is no WIP, processing time or idling time data are recorded. Logistic industry has many manual driven process such as picking, weighting, label sticking and packing goods. The productivity and lead time of the company are directly impacted by the efficiency of the manual procedure. There should be a thorough examination of each step in order to identify any potential bottlenecks.

Case 2 (Electronic Industry)

1. Surface Planarizering Process

- Raise the planarisation capability for board thickness up to 200mil or above
- Equip with rotary scrubbers to improve copper surface uniformity

2. MaxVIA Plasma System

- Processing High performance
- High Aspect Ratio project up to 20:1

3. Post Etch Punching

- Improve punching positional accuracy to +/-0.5mil from current +/-1.0mil
- Improve overall layer-to-layer registration to +/-1.5mil from current +/-3mil

4. Random Pattern Projector (RPP) Laser Process

- Pattern plate line upgrade from DC to RPP to increase aspect ratio capability to 20:1
- Provide more even surface plating thickness to support semi-additive process.

5. ENEPIG Process

- Achieve hardness requirement over LGA area without thick gold
- Also capable to provide good wire bondable surface with the aid of palladium layer

6. Soldermask Development Process

- Raise the soldermask develop capability up to aspect ratio 20:1
- Improve soldermask developing quality by 30%.

7. Bare-board Inspection by operators

- Make instant reaction to release recovery lot
- Pre-alert customer for potential slip-up if Bare-board yield result is below planned figure.

In this scenario, processes 1 through 6 are machine-centric, and all production data can be generated by data record. However, at step 7 of the inspection procedure, it is operated manually. There will be a collection of samples awaiting operator processing. The inspection procedure will be the bottleneck due to the accumulation of work-in-progress.

Implementation Agent: Organiser: Funded by Trade and Industrial Organisation Support Fund, Trade and Industry Department

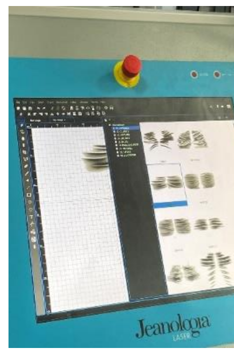
香港模具及產品科技協會 Hong Kong Mould and Product Technology Association

工商機構支援基金 Trade and Industrial Organisation Support Fund

Case 3 (Textile Industry)

1. Raw Material Preparation

- Select materials
- Design printing pattern



2. Laser Marking Process

- Input the design specification, requirement and design layout
- Operate the laser machine

3. Product Collection Process

- Monitor the operation of laser machine
- Collect the laser-processed jeans

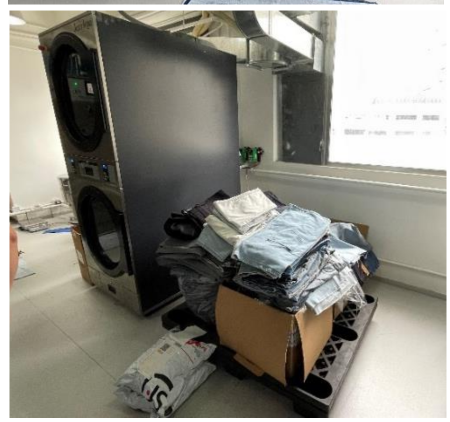
4. Chemical Mixing Process

- Mix washing power, environmental non-hazardous chemical with water
- Generate nano-bubbles for micronization

5. Washing process

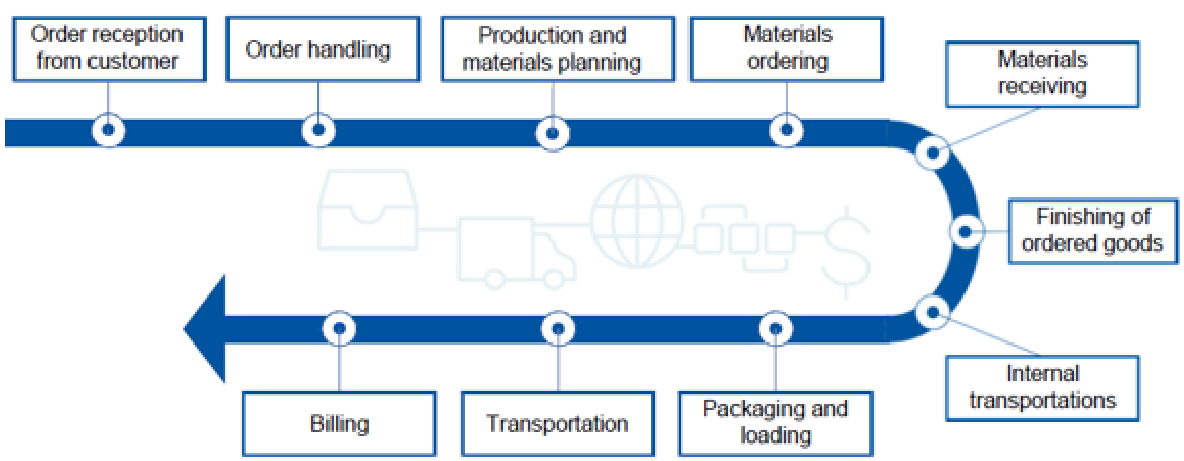
- Control the flow of nano-bubbles
- Combine rotation, stops and mirconization

6. Goods Packaging Process



- Pick the finished goods manually
- Fold the goods and pack the goods

There are various manual processes in the textile industry, including picking, folding, and packing. The effectiveness of a manual process depends on the planning of the production line and the worker's productivity. The aforementioned elements will have an effect on the business's output and lead time. Preferred process for order to delivery:



Case 4 (Toys Industry)

In manual assembly line, in most of the cases in pilot companies, it is observed that their digital and lean management are still have a lot to be improved. Below are some critical points for summarisation.

- Insufficiency of material labelling for lean management
- No system data to support the warehouse operation and onsite management
- No digitalise data, mainly manual data recording and material delivery
- Low transparency of manufacturing data
- Rely on manual operation on arrangement of manufacturing and order
- Lack of collection of manufacturing data
- The actual production operation and planning and scheduling fail to reflect the production progress

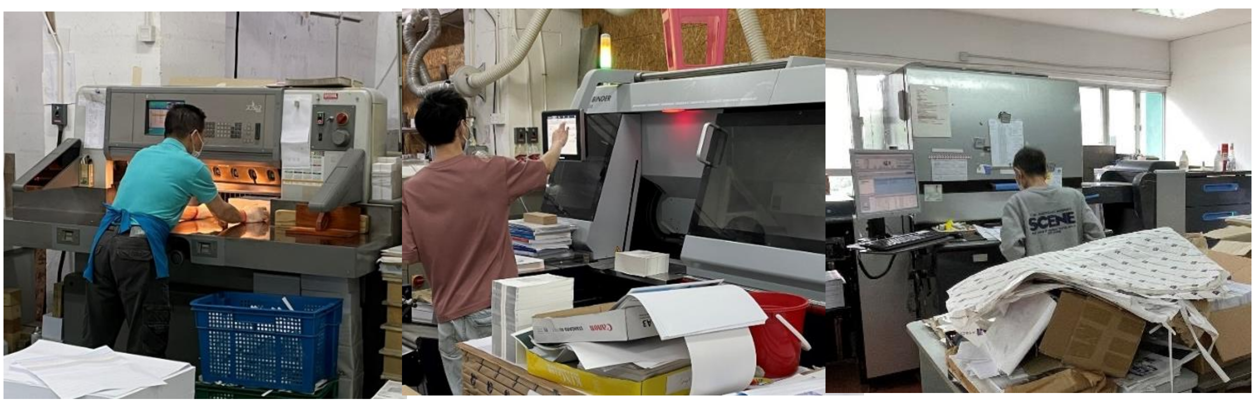


In some pilot company cases, digitalisation is applied in some material and equipment management. Equipment data will be collected and displayed in dashboard for real time monitoring, so that the management team can know the progress of the manufacturing instantly for onsite planning without information and planning latency.

Some pilot companies have implemented QR codes and bar codes as part of their systems for tracking and tracing material and moulding. The management team is able to simply control the products' current state or where they are located. Information pertaining to the handler, as well as consumption rate, location, and the status of orders, will be logged and made simple to monitor.

Case 5 (Printing Industry)

There are numerous manual processes in the printing industry, including paper cutting, binding, digital printing, labelling, machine parameter setup, material transportation and packaging. Observed is some paper product waiting to be processed while sitting idle. In material transportation, some manpower and time are wasted. Some enterprises have powerful printing machines but no system for data integration.

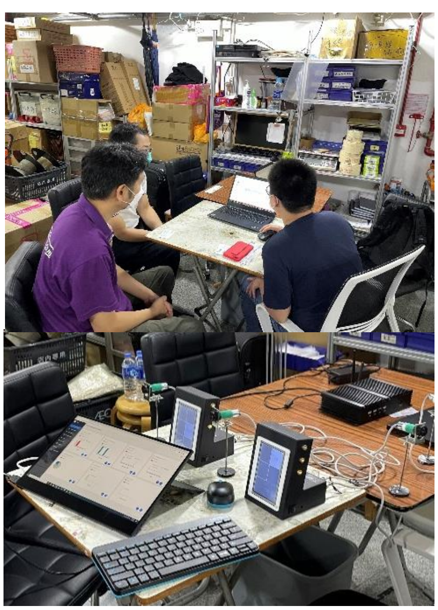


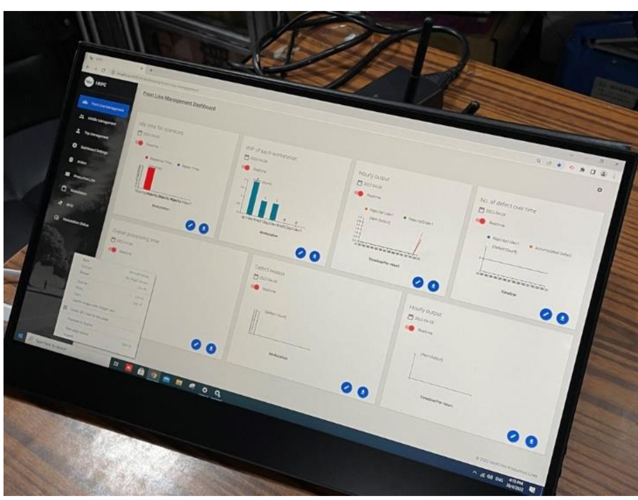
Other than the data from the machines, the data from the manual operations are not recorded. Excel is being utilised by the vast majority of them in order to manage job orders and record data.

Digital Lean Analyser Set up in Assessment

Utilising a digital lean analyser is one of the solutions that can be used to collect real time data in a manufacturing process that is driven by manual work. The infrared sensor of the digital lean analyser will measure each time frame of the process in each workstation, beginning with the time at which the process begins and ending with the time at which it concludes. As a consequence of this, the data pertaining to the processing time and WIP will be generated, visualised, and presented in the dashboard in real time. The manager is able to have rapid access to information regarding the manufacturing status, which allows for more precise planning and monitoring of the manufacturing process.

The following is the onsite set up of digital lean analyser in pilot companies to demonstrate the concept and function of the device.

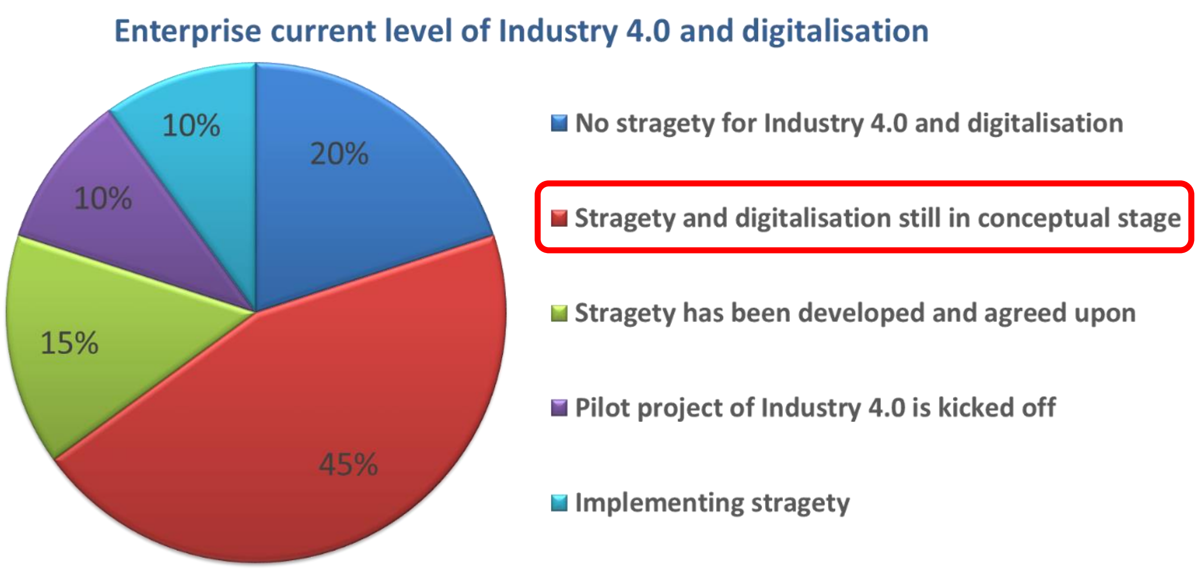




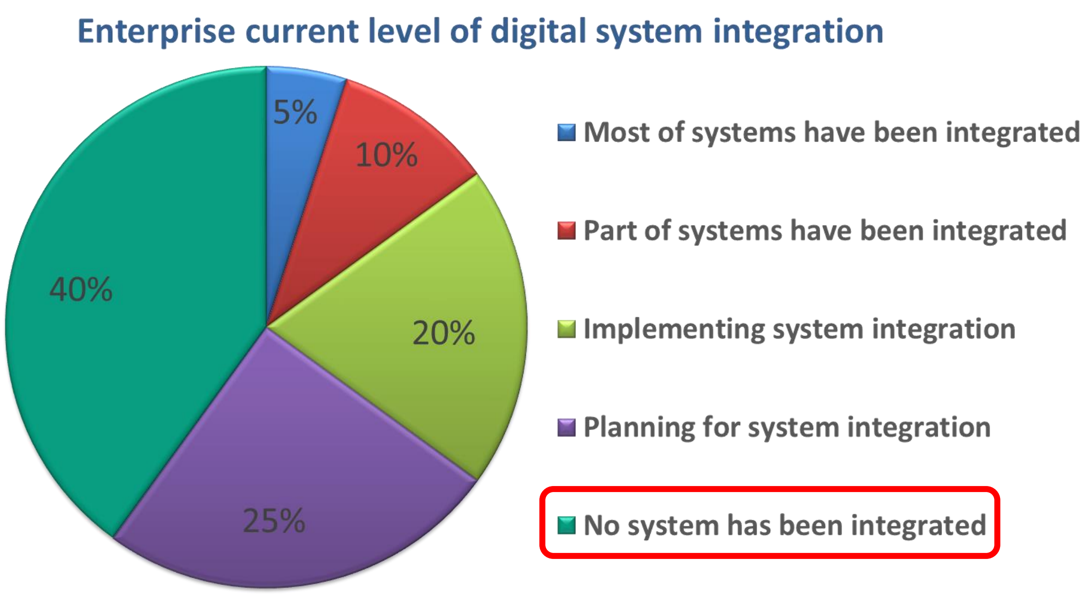
Summary and Expectation of Improvement for Industry

Twenty Hong Kong pilot businesses have been consulted and assisted with Industry 4.0 migration as part of this project. Consideration has been given to industries from the metal, electronics, plastics, and machinery equipment, logistic, food, and textile industries, etc., as well as the maturity level and average of the Hong Kong industry. On the basis of the level of maturity, recommendations for supporting the upgrade of the Hong Kong industry have been deduced and formulated. The following conclusions have been drawn.

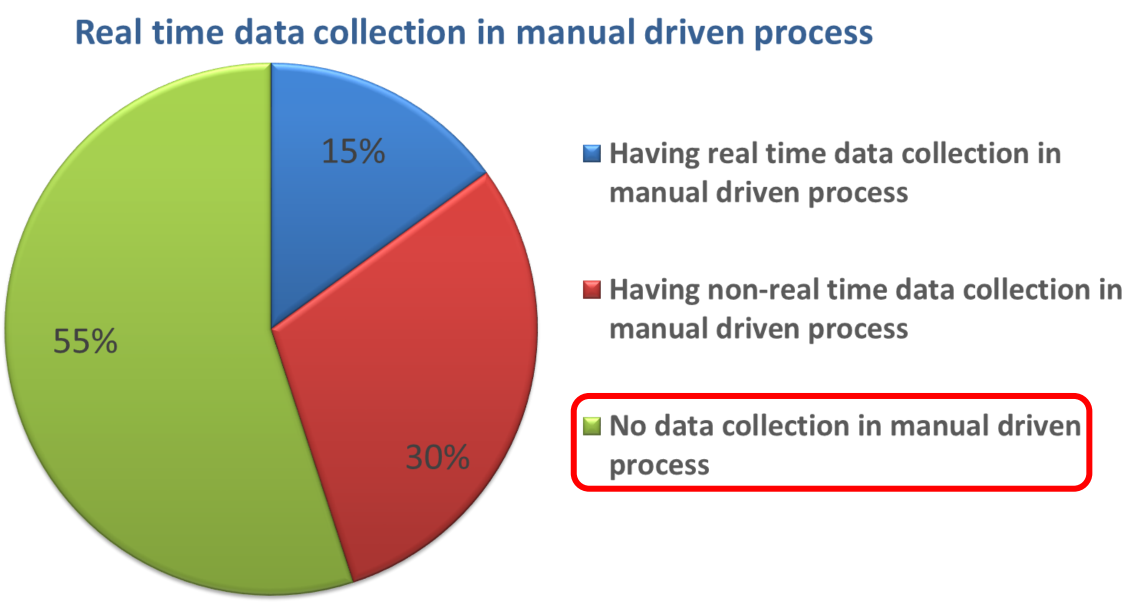
<u>Digital Lean Analysis - Overall Corporate Strategy Level</u>



Most of the enterprises have no complete plan on how to start implementing Industry 4.0 and the are in a wait-and-see situation.

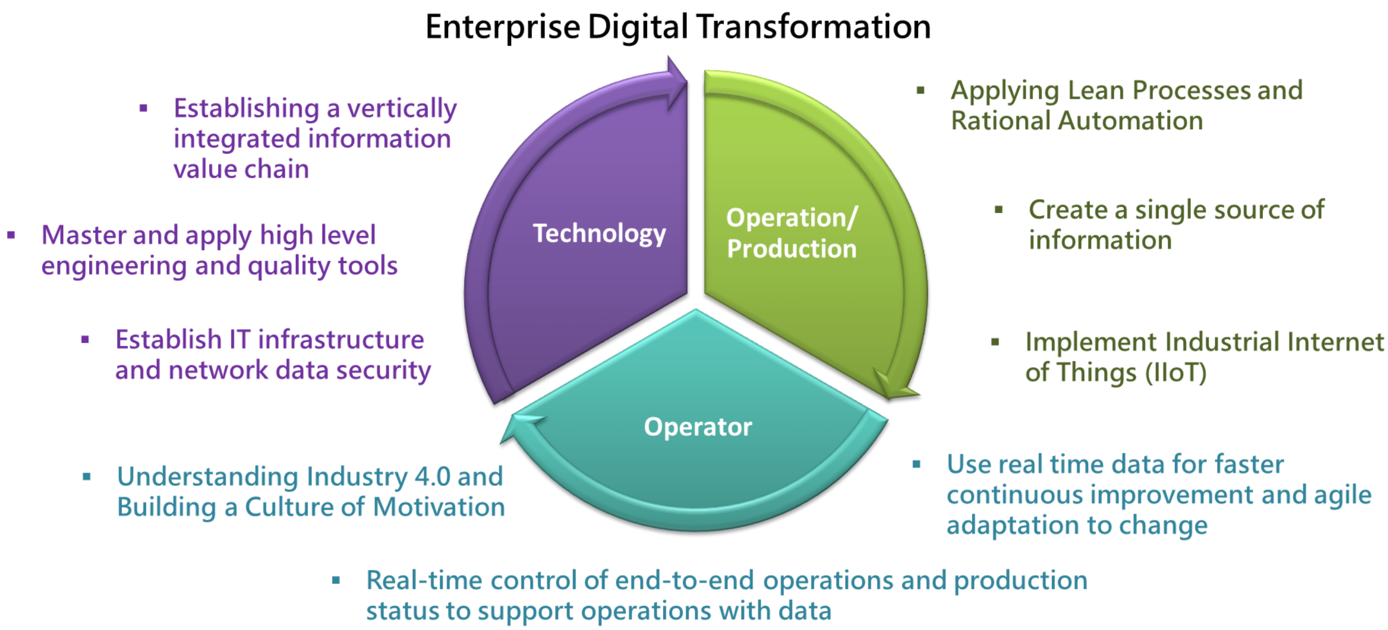


In current level of digital system integration, most of companies have not implemented system integration. Most of them are using different standalone system.



Most of the enterprises have machine data collection but no real time manual manufacturing data such as WIP, processing time and idling time data collection. Some manufacturers will collect manufacturing data manually, for example by counting the takt time during production or monitoring the output rate; however, the data acquired is not the real-time data.

Implementation Strategy of Industry 4.0



On basis of the maturity level, recommendations have been derived and formulated for support the upgrade of the HK Industry. Following insights have been derived:

Below is the

- The strength, weaknesses opportunities and threats, **SWOT Analysis**, of current manufacturers from Hong Kong and

- Outline the current **Industry 4.0 Maturity** and thereby explain shortcomings of the industry and gaps-to-be-closed

SWOT Analysis of Hong Kong Industry

Strength	Weakness
▪ HK Industries show mindset for improvement of operations by methods and technologies from Industry 4.0 ▪ Early adopters understand Industry 4.0 and and see the need for transformation in strategy and organization departments	▪ Processes are not digitalized by software tools, thus, limiting vertical and/or horizontal integration ▪ Missing data transparency and reliability (availability, status, utilization) of the production resources of machines and tools
Opportunity	**Threat**
▪ Transparency in operation by making process steps and machine status visible ▪ Improvements of operations by standardization/digitalisation of processes and application of data analytics	▪ Insufficient capabilities and talent shortage to develop smart machines/equipment and Industry 4.0 Infrastructure

The strength of the Hong Kong Manufacturing Industry lies in the willingness and mind-set in adopting digital and Industry 4.0 methods and technologies. These are best practices from international lighthouses that are adapted to the specifics of the Hong Kong Industry. Most of the management of the SME's from Hong Kong understand the concept of lean and Industry 4.0 and see the need to transform the company. Foremost, the digitisation is understood as a tool to optimise current production operation. However, a holistic understanding of Industry 4.0 such as the value of supplementing traditional businesses by digital business and service models is yet a new concept for most top-levels.

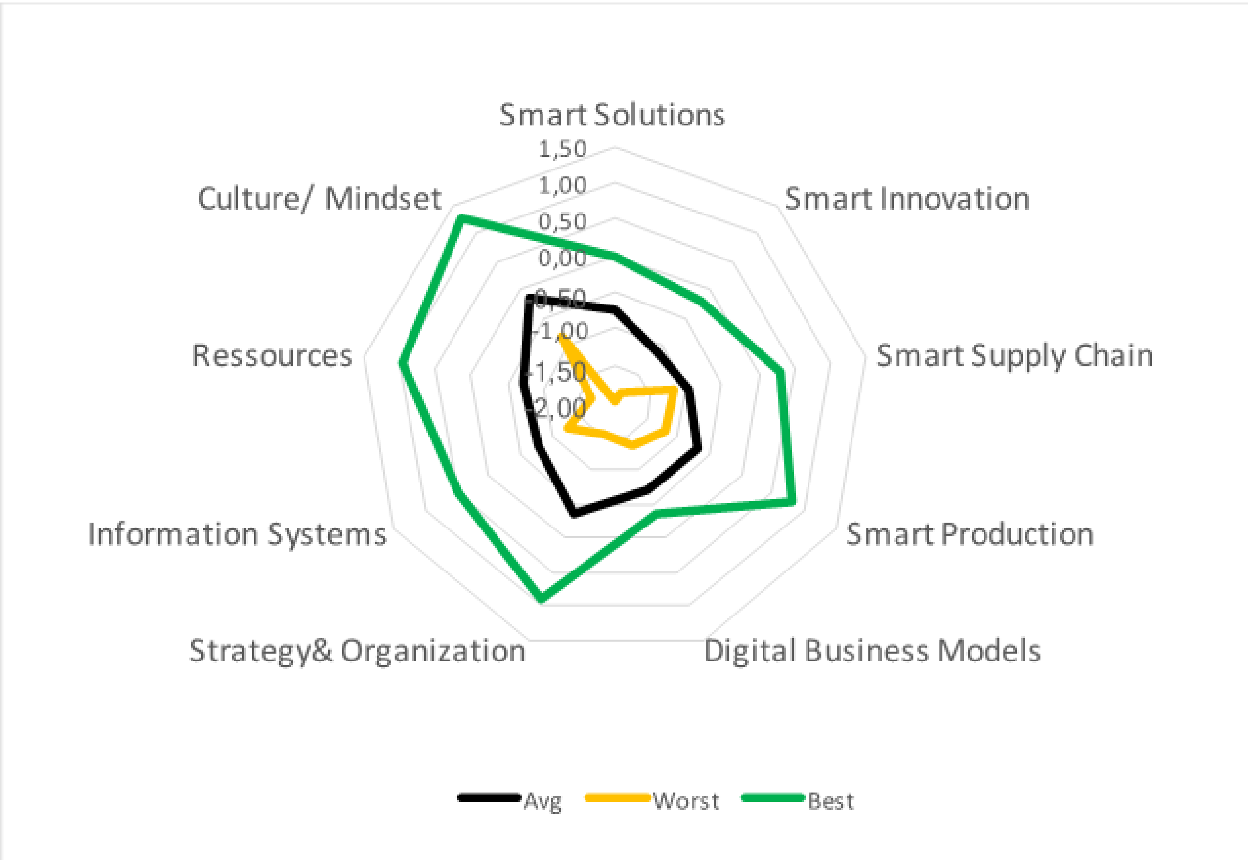
Major opportunities for manufacturers lie in facilitating transparency in operations and establishing an environment of continuous learning and improvement. Particularly in logistics and manufacturing, classic KPI's help to improve operations. In combination with Industry 4.0 these KPI's can be generated in real-time by IIoT sensor and IT infrastructures. Logistics and production processes can become transparent and improved continuously. Furthermore, manufacturing processes can be standardised and optimised by lean principles. The streamlining of processes can be supported by real-time data originating from a vertical and horizontal integrated tool chain.

Today, operations of manufacturing companies are not fully digitalised and lack the application of standard digital tools. Software tools for a vertical integration such as Manufacturing Executing Systems (MES), Advanced Planning and Scheduling Tools (APS) as well as the integration by a corresponding IT infrastructure for handling a vast amount of data are not established yet. The horizontal integration with IT Systems of customers and/or vendors does not exist yet. Due to the limited digitisation of processes, transparency of production has not been reached and improvements cannot be driven based on real-time data analytics. This also means machine and shop floor status (i. e. availability or failure states of machines) are not digitally recorded and/or analysed by production personnel. Historic data are not analysed and used to improve operations in SMEs.

In addition, manufacturing companies lack human resources and capabilities in Industry 4.0. Digital talents are difficult to acquire especially due to talent shortage in HK. Among others, following capabilities need to be developed and/or acquired by Hong Kong manufacturers:

- Hands-on experience and knowledge about digital tools and application in operations, especially production and logistics
- IT-Knowledge of dealing with vast amount of data and setting up and integrating a vertical and horizontal IT Infrastructure
- Capabilities in data analytics for analysing production data, both on planning as well as machine level
- Combining operation/process knowledge with analytics methods and models for continuous improvement

The Industry 4.0 Maturity of the Hong Kong Industry in average is derived and the best/worst case limits are outlined in below figure. Following insights are deduced and detailed in the upcoming paragraphs:



Smart Solutions

Hong Kong Industry creates a variety of goods for both national and internal customers. The vast majority of manufactured goods are primarily mechanical or electrical in nature. Customers are rarely offered service models.

In addition to solitary components/technologies, certain products combine mechanical and electrical components. There are initial steps toward developing a mechatronic product that combines mechanical, electrical, and software components. However, a CPS-based or Industry 4.0 product with a substantial IT and data analytics component does not yet exist.

Some Hong Kong products, particularly in the machinery business, include additional services. These are mostly after-sales services, software maintenance, and upgrades. However, digital business models are not yet widely adopted or implemented. In the equipment sector, sensor systems are utilised for data collection, process enhancement, and user-specific supplementary information. In addition, human-machine interfaces are employed for user interaction.

However, none of the organisations examined utilise data for processing, analysing user engagement with products, and/or monitoring conditions and performance throughout the product's life cycle. There is no use of data-driven analytics and decision-making to enhance the client experience or provide additional services.

Smart Innovation

In engineering and/or production, Hong Kong Industries uses a traditional project management methodology. Processes are planned beforehand and segregated into stages, with quality gates controlling each stage. Rarely is industrial or applied research undertaken with cooperative partners such as applied research centres. The development capacities of manufacturers are constrained, both in terms of product knowledge and production equipment. If development departments exist, they have discipline-specific, standardised software tools with restricted exchange formats. Oftentimes, the product life cycle is not digitised and lacks the appropriate digital tools for project management, cost estimation, and deviation management.

In development and production, Lean concepts are rarely utilised, resulting in inefficiency, waste, and restricted learning potential. While initial lean manufacturing approaches exist, the lean principle has not yet been applied to development.

Since the majority of manufacturers adhere to an OEM business model, there are no customer-driven innovation processes. None of the small and medium-sized enterprises use cutting-edge development approaches like agile development.

In addition, processes (i.e., ideation, prototyping, development, and launch) are not entirely digital, resulting in primarily isolated solutions. Absent is data-driven innovation based on analytics of internal and external data (such as customer usage profile/information). Smart innovation can be used to find out which customer pains should be addressed by adding what functionalities (What?) and the user experience necessary to ensure that the product is usable and liked by the target customers (How?). These steps should be done repeatedly (some of the most successful products on the market have been developed in hundreds of such iterations), and in as small steps as possible, while getting continuous market feedback.

Smart Supply Chain

The majority of Hong Kong industries monitor and trace the material flow. The majority of manufacturers base their material flow on best practices or previous experience, while others employ Auto-ID Technologies like QR Codes.

Frequently, computer systems support warehouses, and inventory is recorded digitally. However, these processes are frequently performed manually (Scanning of QR-Codes).

Lean principles such as value stream mapping and material pull are not fully implemented. This results in excess inventory, disorderly material storage, and inefficient production stocks.

None of the manufacturers utilises advanced data analytics tools for anticipating product consumption, categorising suppliers, or optimising lead times. Manual inputs result in insufficient data collection, inconsistent or unreliable data collection, or both.

Material flow optimisation simulations are not utilised, resulting in inefficiencies on the shop floor. There is no digital link between suppliers and/or customers to provide a real-time exchange of logistics data. Therefore, there is a lack of digital horizontal integration for optimising supply chain networks.

Smart Production

The majority of manufacturers segregate activities based on worker skill set or level. Standardised and partially automated parallel lines (automation of simple logistic/assembly processes).

Over fifty percent of manufacturers have partially embraced lean principles (5S, Pull Principle, etc.). Frequently, KPIs are specified on paper but are not supported by real-time digital sensor data. Some KPIs are not based on worldwide standards, but are instead specifically developed by the operation management of the organisation.

Frequently, industrial machines are not networked, and overall processes are not visible through the use of sensors or IIoT technology. HK Manufacturers are neither vertically nor horizontally digitised. No Real-Time data are collected, centralised stored, or analysed for production optimisation/ enhancement.

On production floors, product orders and configurations are not automatically processed, planned, or implemented. Primarily physical labour and data entry/conversion are required. The production is not yet autonomous and cannot be optimised using technology or methodologies for real-time data analytics.

Digital Business Models

The Hong Kong Manufacturer's business model is well defined and disseminated throughout the organisation. Owners, management, and staff are all conversant with the present business model and operations.

Customers have the option to personalise the ordered goods. The majority of manufacturers are contract-driven OEMs. They are confronted by an increase in orders with a low volume and a significant volatility.

Existing operations are not transparent due to a lack of data collecting techniques and technology, despite their increasing significance. The operations are not assessed in real-time, hence excluding significant advances in operation efficiency and revenue based on digital business models.

The majority of manufacturers do not gather customer information or utilise it for monetisation (i. e. sales or profitability improvement). In addition, chances for business model innovation in the manufacturing industry are unknown. In addition, procedures are barely automated, and decision-making activities rely on experience rather than algorithms or data analytics.

Strategy and Organisation

The majority of Hong Kong's manufacturing enterprises are OEM-based contract manufacturers. Some manufacturers have initiated Industry 4.0 pilot projects, gaining initial hands-on expertise with cutting-edge procedures and technology.

However, a comprehensive digitalisation strategy from the executive suite to the shop floor does not yet exist. Management frequently views the computerisation of operations as less important than physical manufacturing. SMEs rarely include Industry 4.0 into their strategic planning.

Culture/ Mind-set, Information Systems and Resources

Hong Kong manufacturers are aware of the benefits of Industry 4.0. The SME's upper management is eager to implement Industry 4.0, with a particular emphasis on initiatives with a rapid and realistic return on investment.

Nevertheless, SMEs do not completely comprehend the unique strategic and project implications of Industry 4.0. Needed are agile and iterative Industry 4.0 implementation projects with a cycle of measuring, modelling, and analysing sensor-based process data.

Despite the significant interest in Industry 4.0, its application is commonly acknowledged for the logistics and manufacturing departments, but it is not well understood as a tool to improve the organisation as a whole across all departments.

By observing the industry landscape in manufacturing SMEs in Hong Kong, we have developed the following eight overall recommendations for ensuring a highly productive pick-up of Industry 4.0 and digital lean concepts by Hong Kong industry, and for ensuring the digitalisation and lean concept applied on Hong Kong enterprises and leads to make Hong Kong a very attractive venue for headquarters and innovation functions of manufacturing enterprises in an Industry 4.0 world.

Solutions for Common Applications

Across the onsite visited industries several common applications bringing strong benefits have been identified. These include tracking and tracing of materials and WIP, OEE measurement, and basic IoT instrumentation of machine PLCs. Solutions for these applications do exist on the market, but are mostly too advanced and costly for the purposes of Hong Kong SMEs. The development of simpler solutions such as easy-set-up digital lean analyser for real time data collection and solutions focusing more on inventory and lead time optimisation rather than maintenance and quality issues can strongly help Hong Kong SMEs.

Innovation Readiness

Many Hong Kong SMEs are traditionally used to receiving full specifications of a product and responsible mostly for efficient scaling in manufacturing. One of the key elements to sustain the competitive edge of Hong Kong SMEs in an Industry 4.0 and digital lean world is the development of OEMs to first ODMs and then OBMs. However, the development of own products with commercial responsibility for market success requires a very different mind-set, as many more levels of uncertainty ("VUCA" – Volatility, Uncertainty, Complexity, Ambiguity) need to be handled in an efficient and effective way to accept, but minimise inherent risks. This includes using established management methodologies for dealing with innovations (Innovation and Technology managements) as well as creating the right mind-set for innovation. This does not happen in one step, so a Hong Kong model for transforming management methods and mind-sets from OEM business to world-class innovator needs to be developed and suitable professional services offered.

Research for Hong Kong-Specific Advanced Applications

The very low lead times and high flexibility of Hong Kong SMEs are part of their core USPs in international markets. Rising wages and a resulting higher need for automation, as well as more unstable supply chains threaten these USPs. The development of solutions for enabling collaborative automation while retaining flexibility (using advanced collaborative robotics) and handling of unstable supply chains (through AI) can help sustain and even extend these USPs. This includes flexible assembly cells, prediction models for supply chains, and similar industrial AI applications.

Fundamentals for Higher Maturities

Above Visibility (1i) Maturity level, the use of data in day-to-day workings by a large number of staff is integral to leveraging the benefits of digital lean and Industry 4.0. Otherwise expensive technology to be aware of the current state of operations will have been put in place without the capability to use it to optimise operations on a daily basis. This requires new levels of personal responsibility from each employee to maximise the benefits for the company, and training in capabilities including cross-departmental collaboration, continuous improvement, data handling and understanding, and problem-solving; on all different hierarchy levels from supervisors to executive level.

Promoting Industry as a Career

In an Industry 4.0 world, industrial companies including SMEs thrive on talent. Employees on very different levels (managerial, professional, technical) need to be trained in understanding data and information, and reacting to it in the most efficient way for the company, as well as trained to generate, evaluate and implement own innovative ideas from small improvements to product ideas. In Hong Kong, Industry does not have an image of a career one can aspire to. Curricula need to show the advanced technologies, creative way of work, and career potentials possible in manufacturing industry in an Industry 4.0 world to attract the best talent to industry.

Infrastructure for Leveraging Hong Kong's Unique Position

To sustain and attract manufacturing companies to have their (regional) headquarters in Hong Kong, it is necessary to provide infrastructure beyond the international appeal of Hong Kong and its legal system. This infrastructure needs to facilitate orchestrating supply chains from Hong Kong and to foster product innovation in Hong Kong. Prototyping facilities for building production-quality prototypes of new products at very high speeds, and data infrastructures for orchestrating supply chains with an ecosystem of professional services around supply chains (e.g., a "Hong Kong Manufacturing cloud" seamlessly connected to supplier and consumer IT infrastructure, together with professional services for tracing supply chains and certifying quality) can strengthen the USPs leading headquarters and innovation functions to stay or return to Hong Kong.

From Demonstrator to Use-Case: Learning in Real Settings

To understand Industry 4.0 not only the technical perspective, but also the mind-set aspects relevant to achieving productivity gains through data need to be understood. Both of these aspects are best taught along real-life use cases showing the difference between a classical production and Industry 4.0 approaches. Demonstrators highlighting Industry 4.0 showcases help illustrate the concept, but do not suffice to teach the interactions and processes needed to fully utilities a full Industry 4.0 implementation in a complex, real production setting. To this extent, it is necessary to develop real use-cases in factories and logistics shop floors in Hong Kong – or designating a specific "learning shop floor" and fitting it with suitable use-cases. Collaboration with the appropriate educational institutions to train the Industry 4.0 concept along these real use-cases ensures quicker pick-up of the relevant skills.

Detail Implementation Roadmap From 1i to 2i

The application of the Industry 4.0 Maturity Index within a company, helps to develop tailor-made digitalisation roadmaps for the introduction of Industry 4.0 to transform the company into a learning, agile organisation. Agility provides a company with the ability to adapt rapidly to changing environmental circumstances, and in the more far-reaching sense even to fundamental systemic changes, for example regarding the company's business model.

Through the introduction and development of Industry 4.0, manufacturing companies are capable to significantly reduce the period between an event and an appropriate action.

The road to Industry 4.0 is individual for each company. First of all, the individual starting situation must be identified, analysed and objectives must be defined.

The introduction of Industry 4.0 represents a significant expansion of the digital skills and abilities to manufacture companies and is embracing change in many parts of the organisation. Therefore, a step-by-step approach has been developed to support the transformation process within the company by not radically changing the whole company but slowly focusing on the most critical aspects.

Therefore, in the first step, an analysis of the already applicable levels is needed, and afterward, a stepwise approach can be used to reach higher and more efficient levels of Industry 4.0. In general, there are four questions that support the identification of the right industry 4.0 level. Starting with the visibility level that focuses on the question: “What happens?” It is about seeing the actual data and enhancing the data availability.

When the next level of industry 4.0 is reached the following question can be answered "Why does it happen?" – based on the available data one can analyse and understand why a specific event occurred.

The next level is already more advanced and includes the ability to predict. Asking the question "What will happen?" – if a company is able to answer this question based on a data set and can prepare themselves for specific events the level of predictability is reached which is marked by the improvement of predictability through established patterns and realistic models.

The so far highest level which can be reached is adaptability – focusing on self-optimisation of processes and applications. The leading question of this level is "How can an autonomous reaction succeed?" – whereby the decision which is made bases on smart available data.

In many companies today it is still often the case that in some areas not even the first question "What happens?" can really be answered with the help of collected data or that different levels are reached in different business areas.

To understand it more clearly, we will first describe and subdivide the Industry 4.0 Maturity level individually in more detail.

Not Ready (-2):

The level represents processes from Industry 2.0 and 3.0 predominantly. This means the company uses the division of labour by an assembly-line work environment. Eventually, first programmable controllers/logic are introduced in order to control and automate process steps.

Computerisation (-1):

The first level describes the starting point for the development path to a real industry 4.0 company and assesses the basis for digitisation, which is the company's computerisation. This Level describes the isolated use of information technologies. It is already well advanced in most companies and is primarily used to perform repetitive activities more efficient. The computerisation represents a considerable benefit: It enables a low-cost, low-error production and allows for a precision that allows the manufacturer to produce many new products.

Nevertheless, companies still have a large number of machines without a digital interface. These often have long lifetimes or are equipped with manual operation.

Connectivity (0):

The level represents the basic formation of a company towards Industry 4.0. The company provides well-functioning processes in all departments. Engineering and Production Processes are optimised based on lean management/production approaches. Manufacturing processes are simple and can be measured (i. e. less inventory). A mind-set for continuous improvement is embraced on all levels of the company hierarchy. Mostly, there is no troubleshooting, and the process goal can be reached in time with it is according to quality requirements. The company embraces Industry 4.0 approaches and has a willingness to integrate and adapt towards best-practices from Industry and Research.

Real-Time Information Generation (1i):

Sensors can capture processes from beginning to end with a variety of data points. Processes and states can no longer only be recorded in individual areas, such as a production cell, but throughout the entire company in real time. The data in the value chain of the company can be automatically measured by sensor equipment and provided to a standard and company-wide database. The data is available in real-time and acquired without manual labour. The data within the company is consistent and provides a single source of truth. The IT-Systems are integrated, vertically, and horizontally along with the automation pyramid.

A digital shadow of the data already exists. In many cases, the data collected is only made available to a small group of people who are directly involved in the process. Further use of the data beyond the specific process often fails due to system limitations.

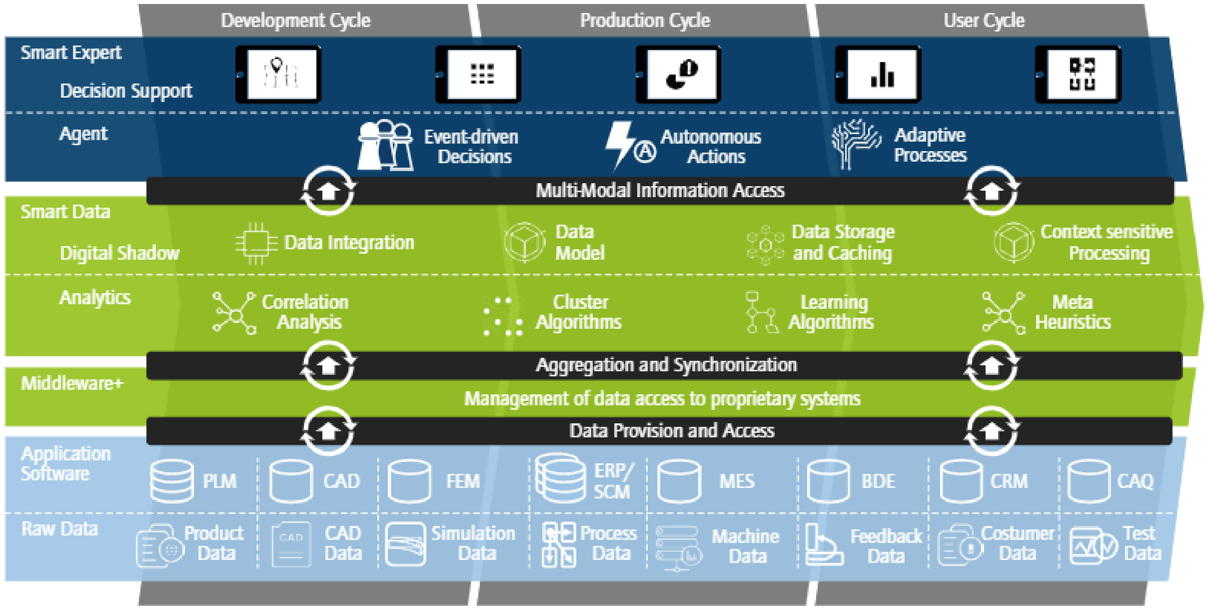
Real-Time Information Processing and Integration (2i):

The following level focuses on the data, which is aggregated in a company-wide database. The integration of IT enables data fusion and a common data set for analytics and forecasts (i.e. predictive maintenance). In order to recognise and interpret cause-effect relationships in the digital shadow, it is necessary to analyse the collected data in the respective context and to apply engineering knowledge. The semantic linking and aggregation of data to information as well as the associated contextual classification represent the process knowledge required to support more complex decisions. Additional knowledge can be compiled due to predictions and modelling. Transparency is generated about specific operational processes and sequences.

Integration of Cyber-Physical Systems (3i):

The 3i level enables the forecasting capability to simulate different future scenarios and identify the most likely ones. The company uses mobile assistance systems for making decentralised decisions. The human-machine interfaces (HMI) are matured in all processes leading to efficiency and quick response times for the operators (i.e. in case of emergencies). Machines and robots are cooperating in order to work on a standard process step (and goal).

This stage enables companies to anticipate future events, make timely decisions, and initiate appropriate response measures.



Intelligent, Autonomous, and Self-Organised Processes (4i):

For the last level, the forecasting capability is the prerequisite for automatic action and self-optimisation. Traditional manufacturing transforms towards an intelligent and autonomous production environment. Cyber-Physical Systems (CPS) automatically control and act autonomously. The production has a high degree of automation, is self-learning and continuously optimised its processes and products.

The final level is reached when the respective company can use the data of the digital shadow in such a way that decisions with the greatest positive effects can be made autonomously and without human intervention in the shortest possible time and the resulting measures implemented.

1i – Visibility

Product state

By integrating communications devices, it is possible to communicate product state back to the vendor. This enables new business models such as pay-per-hour, but also enables generating statistics. This upgrade option is very common in electronics, where anyway power and connectivity are provided, but can also be used for machinery or household devices. This option needs communications interfaces to the Internet (e.g., WIFI or a mobile network adapter) and connection to the product's own electronics. Furthermore, a (possibly cloud-based) back-end system to register the state information is needed.

Perceive Environment

Adding sensors to perceive environmental conditions (Is a user present? Is there danger?) is a common way to improve safety and energy efficiency in smart devices. If the specific conditions to perceive are known in advance, it can usually be done simpler than the default option of using cameras and image recognition. Often, simple proximity sensors or other stock sensors can fulfil most functions as well. This is very common in machinery, and common in electronics. It could also add value in toys. This option needs suitable sensors and control logics, as well as a means to output required information either via connectivity to a network, or by integration of actors or signals.

Access External Data

Some products benefit from having a link to outside data where they can get information for their operation. This can range from checking the weather or online databases to getting updates and daily greetings, and is applicable for electronics and machinery. It may also be applicable to toys and household devices. A connectivity module to the Internet is needed, and a link to an API containing the relevant data. However, it is not necessarily needed to have an own back-end if the required data is publicly available (like weather or traffic information).

Distinguish and Authorise Users

Products with complex user preferences or with safety- or security-critical components benefit from user identification. This is common in machinery and electronics. Users can be identified using anything from selection from a list, username/password or PIN entry, or biometric features. This needs an input/output module of some form or biometric sensors, as well as a processing unit storing user profiles and reacting to use by different users. Internet connection can help to reuse user profiles or information from cloud services, which is often more user friendly.

2i – Transparency

Product Usage Analytics

Analysing how people use a product can help identify sales potentials and deliver better and more individualised service to customers. This applies to electronics, but can also apply to machinery and toys or household devices. Very basic analytics can be done within a product (for instance when having text entry, learning the writing style of a user to make text entry faster, or learning the most used functions of a user to optimise menu screens for them) but more sophisticated analytics require a back-end platform for devices to connect to. Next to input/output capability, for some applications like voice or image recognition, sufficient computing power in the product is needed.

Condition Monitoring

Monitoring the condition of a product allows for better maintenance or replacement scheduling and allows to offer services around the product. It is common in machinery, more expensive household electronics and cars, as well as consumables. Sensor integration to measure the condition of the product is needed, although in some instances simple usage counters or timers suffice for basic functionality. A maintenance model for the product needs to be made before, and for best results should be continuously updated based on real data, for which the product needs internet connection and a back-end service.

Provide Interfaces

Many products provide data or functionality which can be used to realise things the product manufacturer did not think of, but which adds to their value. The prime example are smartphones, which are only as valuable as they are due to sophisticated app stores bringing the innovation of millions of developers to every device. However, any product can provide an API, either through direct communication or via a cloud back-end, and let other developers leverage the functions of the product.

Integrate with Systems/Persons/Platforms

The value of connected products rises above proportion to the number of other devices they connect to in a simple way. Integration within product ecosystems such as Smart Home or Smart City systems is most prevalent in infrastructure goods, but developing in home electronics and machinery. Support of multiple standards and protocols is usually key for being able to address large enough markets. The product can also function as an adapter between different systems, in which case often multiple communications interfaces are needed.

Digital Lean Challenges and Limitations

Manufacturers frequently get caught up in a digital program that examines a technology rather than tackling the most pressing business challenges while integrating new technologies. Poorly focused technology projects and process improvements might result in program weariness ("pilot purgatory" or "random acts of digital") and even negative economic returns. This may be prevented by undertaking a thorough assessment, ensuring that efforts are aligned with areas where value can be captured, and building strong business cases that can be tracked throughout implementation. Each separate project should aim to improve agreed-upon operational measures (or key performance indicators) that may be connected to monetary gains. Metrics should be tracked and reported as initiatives are implemented to ensure program value is captured.

The Industry 4.0 era allows us to access a lot of data, arising from sensor, Industrial Internet of Thing (IIoT) and social networks. It is challenging to know how to use these technologies to build the fundamentals of lean thinking and enhance industrial productivity. Specially, data needs to be visualised, reusable and delivered to the correct person, in a suitable format, at the right moment. Therefore, lean thinking with digital promotes data visualisation and just in time delivery and also information usage. Integrating digital technologies with lean manufacturing seems beneficial. However, manufacturers need to realise how to integrate the lean concept with digital technologies from data acquisition to investigate the human machine interface (HMI). Human resources are required to be managed these challenges by figuring out the context from which data arises, translating data languages, interpreting the data and deciding proper analysis methods.

In “data-driven” problems, hidden data needs to be extracted and used to explain or solve situational problems. In “problem-driven” situations, data needs to be extracted from proper sources and used for hypothetical testing. In different cases and situations, right knowledge, right person and right moment are required to deal with. It is also important to understand the definition and measurement of the industrial productivity in the context of digital lean.

Before practicing a digital lean effort, it is necessary to define the right starting point. Usually, enterprises will select a well-understood production line to study and focus on. Inside the production line, the exact starting point will be chosen after the work of evaluation of human, proves and technology readiness has done.

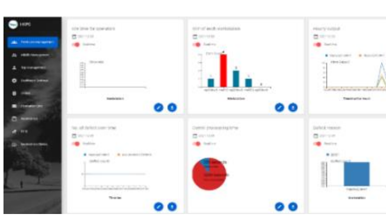
Apart from the development of technologies, human side is also an important fact for digital lean transformations. Digital lean transformations require individuals to adopt new methods of working, deciding, and behaving. People need to learn and be trained to adapt the change in management. It is resistant for operators and workers to change how they have been working for many years. They need to get used to change the decision making mind-set by shifting from experience based to data based. With the adoption of Lean Industry 4.0, the development and training of front-line personnel has greater significance, as these workers must be prepared for the new ways of working and engaging with technology. For instance, line workers, not engineers, must be able to train collaborative robots that work with them. Top management needs to consider to change the management program in place to guide the transformation.

Digital lean strategies frequently necessitate a strong technological base. The facility, for example, must have adequate network access and be able to alter whether crucial process data is currently taken from machines or other phases of the process. If that's the case, it must determine whether the data is digestible in a format. One of the essential elements to becoming digitally lean and enjoying the previously mentioned benefits is enabling technology to capture data.

Way Forward for Industry 4.0 Digital Lean

Licensing Digital Lean Technology Partner

The digital lean analyser developed by HKPC is licensed to i4.0 Digital Lean Technology Partner – WITTI Technology Limited. They will help promote the digital lean technology in Greater Bay Area in order to resolve the pain point of the factory. According to the research, The Greater Bay Area factories are suffering resource wastage that a factory with 500 employees wastes 200,000 hours per year, which is equivalent to RMB 5 million. And their implementation of Industry 4.0 is only focusing on the Internet of Things (IoT) of equipment, ignoring the digitalisation and real-time optimisation of manual processes, which ultimately fails to fully solve the pains of enterprises and improve overall efficiency. When digitalization technology is used in factories, it is expected to increase the rate of productivity by 20% and the rate of machine utilisation by 25%. It is also expected to reduce the defect rate by 40% and save 1 million RMB annually.



i4.0 Digital Lean in Metaverse for Virtualised Process Optimisation

Digital Lean Technology can be implemented in a variety of contexts to develop and grow diverse businesses. Among them is the Metaverse. HKPC has built an i4.0 Digital Lean in Metaverse for Virtualised Process Optimisation. It is a novel application for production line optimisation performed in the Metaverse. It implements HKPC-patented i4.0 digital lean methodology based on actual production line settings. A wide range of parameters, including labour and manufacturing conditions, can be adjusted and analysed for optimising a production line virtually and efficiently.

It rides on digital lean ideologies, one of the key Industry 4.0 technologies to optimise production efficiency and reduce waste. All production data of the virtual production lines will be generated and analysed so that bottlenecks are found ahead of time, and further adjustments can be performed at an early stage. The required time and costs in the physical world for the Plan-Do-Check-Act, lean improvement or production testing can be significantly reduced.

Both time-saving and cost-reduction are driven by system intelligence and data analysis in the Metaverse. The application does not involve any physical equipment and is not restricted by geographical limitations in the real world. With this application, production optimisation can be performed remotely.

- Working mechanisms and theories:

This application involves both hardware application and software development. A virtual factory with a digital lean production line is built on the Metaverse platform.

With the use of all four key enablers of Industry 4.0: smart sensor, Human Machine Interface, data and network, the Metaverse platform can re-create any digital lean productions and solutions, with all the production data being collected, analysed and visualised in real-time.

Furthermore, a cyber-physical analysis can be performed if a physical production line has already been set up with a Digital Lean Analyser, an award-winning technology patented by HKPC. The results of the line balancing in real life can be imported, while the results in the Metaverse platform can be exported for comparison and help further optimise the setup.

With this application, multiple users can connect to the virtual digital lean production line in the Metaverse through head-mounted displays (HMDs). The virtual production line is manual driven, with two roles for the users: worker role and manager role. Users in worker roles will be trained as workers in the assembly workstation before entering the production line. After training, users will be placed in the workstation to perform the assembly process. Their action and production data will be collected and visualised in the dashboard in real-time. Users in manager roles can review the production data and perform adjustments to improve the efficiency of the entire production line.

The adjustable process and environmental parameters include machine processing parameters, jig and fixture holding operation, the height of the production line, production line speed and environmental factors such as lighting, humidity, temperature, etc.

- Benefits:

i4.0 Digital Lean in Metaverse is a technology that enables the visualisation of physical "Digital Lean" production, allowing factories to lower trial costs by first completing line balancing and testing in the Metaverse and avoiding the excessive time and costs spent on physical equipment and facilities setup when compared to the traditional trial and error optimisation method. The virtual production line in the Metaverse will also perform accurate and true-to-life processes. Thus, the necessary parameters and accurate improvement insights can be directly applied to the actual production line. The overall ramp-up time has significantly decreased.

Also, the virtual engineering enabled by digital lean can help manufacturers strengthen the overall occupational health and safety and reduce risks in the workplace. By creating ergonomically and appropriately designed workstations and steps along the production line, the health and safety of the workers are well catered for, and this is how the new concepts of “i4.0 & Beyond” and “human-centric production” can be realised.

Furthermore, this application encourages people to explore possibilities of revolutionising manufacturing processes by taking advantage of the Metaverse. In the past, manufacturers may have to acquire different types of machinery to improve their productions, with the risk of not achieving a satisfactory outcome. A recurring trial and error process, which is time-consuming and cost-intensive, was used. With this innovation, manufacturers can easily try out different machines and match them in order to find out the optimised configurations. By building up a module of configurations and machinery combinations, the system will continuously get better with time.

- Limitations and room for future development:

There is no limitation to this technology as everything is built in the virtual world. However, all applications in the Metaverse and their interactivity functions rely heavily on the support of the information and communications infrastructure. Therefore, the network stability and capability, back-end computing power, memory storage, computing & stability of all involved peripheral devices are the actual limitations for the development and actual usage of the said technology.

The application currently only services the planning of a factory production line, the earliest phase of a production line's lifecycle. The platform was built in a way that eventually allows for the holistic coverage of the entire life cycle during operation, maintenance, and upgrades. Operations can be simulated and provide real-time factory management through the developing digital machine twins.

Industry 4.0 Digital Lean in Metaverse is a novel application that virtualises the HKPC-patented "Digital Lean" technology for optimising production processes in factories. Virtual labour-intensive production lines built in the Metaverse help manufacturers achieve line balancing and fine-tune their productions. Leveraging the potential of the Metaverse to bridge the gap between virtual simulation and the traditional trial and error methods that are commonly implemented, users can enjoy the best of both worlds due to its user-centric operation, which ensures more accurate and relevant production data be collected. The Industry 4.0 Digital Lean in Metaverse will keep the trial costs low due to no actual purchase of any machine. It directly addresses the pain point of manufacturers during the early stages of production. It allows them to experiment and explore possibilities of new and optimised production methods in a realistic setup before committing to high initial investment costs. This application would also foster Industry 4.0 manufacturing advancements for its countless customisation possibilities and a big step toward a fully remote factory management.

Conclusion

For Hong Kong Enterprise to implement industry 4.0 at varying levels of adoption and company status, they must have the requisite knowledge and skills. Digitalisation and Lean management are the fundamental setup and crucial factor toward the era of Industry 4.0. The lean concept's philosophy and ideas provide the foundation for an efficient and productive manufacturing system. With the help of digital technologies, the production system becomes more efficient and productive. Rather than the traditional way, it generates more accurate, precise, and real-time data for operation and management. Digital lean technologies provide a way to find out and reduce waste and cost in the manufacturing stage, making management, process, and operation more efficient and effective, putting enterprises in a more productive and competitive position. Typically, digital lean is effective and resilient. It can shorten the time required to comprehend operations and produce more accurate, precise, and timely data. It encompasses re-evaluating current processes with a digital perspective, modifying behaviours, and transforming decision-making from experience-based to data-based significantly more effectively than lean methods alone could ever do. Moreover, focused, purposeful digital lean initiatives may not necessarily necessitate substantial up-front expenditures to yield results within weeks. It is hoped that this guidebook can help the Hong Kong enterprises in better understanding the form and direction of new solutions, the effectiveness of implementing Digital Lean, and how to self-assess their businesses in Hong Kong in order to select the best solution and strengthen their understanding of Industry 4.0 and Digital Lean.