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Flexible Manufacturing System in Penang Electronics and Electrical Industry

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ABSTRACT

This study investigate the implementation of Flexible Manufacturing System (FMS) within the Electrical and Electronics (E&E) industry in Penang. Operating in a volatile global market, many E&E companies in Penang are implementing FMS to maintain their competitiveness. However, an actual understanding of the real FMS industrial practices has been lacking. The objective of this research is to investigate the actual FMS industrial practices of E&E companies in their manufacturing operations. A qualitative methodology was employed to address this gap, involving factory visits, observation and semi-structured interviews with eight factory managers from different E&E companies in Penang. The collected data were analysed thematically through prior codes matching to identify key patterns. The findings reveal the realities of FMS implementation in practice. While companies have implemented FMS principles, they face significant challenges. These include high capital investment and a pronounced skills gap within the workforce. In conclusion, the research demonstrates that FMS implementation necessitates a holistic strategy, addressing not only technical aspects but also human resource development on skilled workers for FMS implementation. This study offers valuable, practical insights for industry practitioners seeking to understand FMS. It also provides information for potential company decision makers to create targeted supporting programs, ultimately aiming to bolster the competitiveness of its E&E company through FMS implementation.

Keywords: Flexible Manufacturing Systems (FMSs); Electrical and Electronics (E&E); Penang; Industrial Practices, Practitioners[1]

INTRODUCTION

The electrical and electronics (E&E) industries in Malaysia aims to strengthen the national manufacturing ecosystem, particularly in semiconductor production, solar energy, light emitting diodes, storage technologies and electronic manufacturing services. In 2023, the E&E industry contributed RM575.5 billion to Malaysia's export, accounting for 40.4% of the country's total exports for that year. According to Semiconductor Equipment and Materials International (SEMI), Penang contributes approximately 8% of the global back-end semiconductor output, establishing it as a leading global location for microelectronics assembly, packaging and testing. Penang's vibrant E&E ecosystem, supported by a network of over 4,000 well-diversified and competent local suppliers (Invest Penang, 2025), has been a key factor in attracting significant investment.

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As a cornerstone of the Malaysian economy, Penang's E&E industry operates in a volatile global market. Consequently, many E&E companies in Penang are implementing Flexible Manufacturing System (FMS) to maintain competitiveness. However, a clear understanding of the real FMS industrial practices has been lacking. This study investigates the implementation of FMS within Penang's E&E industry. The research objective is to investigate the real FMS industrial practices by eight companies in their manufacturing operations. The research is conceptually inspired by Hughes and Hegland (1983) who advocated that "in defining FMS, what is important is the understanding of what FMS represents conceptually, and what it means to a company in terms of manufacturing strategy". Therefore, by revisiting classical FMS theories and tracing the evolution of FMS since its identification in 1973, this study focuses on investigating the real FMS industrial practices implemented in the eight Penang E&E companies.

LITERATURE REVIEW

Despite significant interest in Flexible Manufacturing Systems (FMSs), there is no uniformly agreed-upon definition for the term. The primary feature distinguishing an FMS from traditional manufacturing systems is its "flexibility" (Gupta and Buzacott, 1989). One of the most cited definitions of FMSs is by Ranky (1983), who defines an FMS as a system that handles high-level distributed data processing and automated material flow. This is achieved using computer-controlled machines, assembly cells, industrial robots and inspection machines, integrated with computer-controlled material-handling and storage systems (Kaighobadi and Venkatest, 1994).

While the scope and variety of FMS applications are debated, the core components and characteristics described across the literature are generally consistent. These include: (i) Computer Numerical Control (CNC) machine tools, (ii) an automated material-handling system, and (iii) an overall control system that coordinates the machine tools and materials handling to achieve flexibility (Davis et al., 1989).

The specific manufacturing situations suitable for FMSs adoption were identified as early as 1973. Darrow (1987) outlined the following FMS scenarios: (i) the machining of a variety of high-precision parts, (ii) the requirement for a relatively large number of Direct Numerical Control (DNC) or CNC machines, (iii) the use of an automated material-handling system to transport workpieces into, within, and out of the FMS, (iv) the use of online computer control to manage the entire FMS under varying production mixes and part priorities.

Furthermore, an FMS is capable of randomising the routing of parts, moving them dynamically between work stations rather than in a fixed, straight line. Within an FMS, numerically controlled machines are computers-directed, parts are handled by robots, and finished products are transported via automatically guided vehicles. Automatic tool-changing systems are utilised. When engineering or design changes occur, they are incorporated directly into the controlling computer programs or databases (Kaighobadi and Venkatest, 1994).

Impetus for Change from Conventional Manufacturing Systems to FMSs

According to Maller (as cited in Kaighobadi and Venkatest, 1994), two primary issues preoccupy manufacturing managers: a concern for quality and cost reduction. This necessitates systems that allow manufacturers to pursue these two goals traditionally considered conflicting, specifically high-volume and low-cost production that can response to rapid market changes (Yilmaz and Davis 1987).

It should be noted, however, that the interest in factory automation is not new (Buffa, 1984). An initial period of interest during the 1950s declined, rose again in the early 1960s, and subsequently waned, with little attention shown by 1973. By the 1990s, the automated factory concept saw a renewed interest in both academic and industry press. This time, however, technological advancements in computing, robotics, and other areas of advanced manufacturing brought the 'factory of the future' closer to reality than ever before. The main driver behind this new surge of attention directed towards FMS and other automated system was intensified competition, particularly on an international scale. The main incentives were reduced production costs and enhanced adaptability to an ever-changing market environment (Kaighobadi and Venkatest, 1994).

Empirical studies from the period quantify the benefits of FMS adoption. According to Khlahorst (1981), companies that installed FMSs reported benefits falling into three categories: (i) cost reduction programmes (55 per cent), (ii) market response improvement (30 per cent), (iii) increased production flexibility (15 per cent). Furthermore, Salomon and Beigel (1984) compared FMS with conventional manufacturing technology, demonstrating that FMS provides significant productivity improvements, as summarised in Table 1.

Finally, Yilmaz and Davis (1987) presented propositions regarding flexibility, productivity, and quality. Their investigation found that FMS investment leads to reduced labour costs, increased output, decreased manufacturing costs, enhanced flexibility, and shorter production lead time.

Table 1: Comparison of How Machine and Work parts Spend Their Time in the Shop of a Conventional System and in an FMS Using Optimistic-Pessimistic Format

Parameter	Conventional system performance	FMS Performance		
		Pessimistic	Most likely	Optimistic
Percentage of machine time the machine spends without parts	50	35	20	5
Percentage of machine time that there is a part on the machine	50	65	80	95
Percentage of time that the part is not being worked on while on the machine	70	35	21	7
Percentage of time that the part is being worked on while on the machine	30	65	79	93
Percentage of manufacturing lead time that the part spends either moving or waiting	95	92.5	90	85
Percentage of manufacturing lead time that the part spends on the machine	5	7.5	10	15

Reference: (Klahorst, 1981).

Installation, Implementation and Integration of FMSs

The appropriateness of an FMS for a given production environment must be established before investment commitments are made. Klahorst (1981) provides a clear analysis of the installation and integration process, outlining the following circumstances that justify FMS installation: (i) when part size and mass exceed jib crane standards, (ii) when production volume exceeds two parts per hour, (iii) when processing requires more than two machine types to complete a workpiece, (iv) when more than five machines are required, (v) when phased implementation is planned, allowing material-handling provisions to be incorporated from the start to avoid establishing inefficient practices. The more of these conditions that are present, the greater the incentive for transforming a conventional system into an FMS.

Blumenthal and Dray (1985) advise manufacturers to use simulation to discover potential problems in FMS operations. Simulating an FMS can (i) reduce installation costs, (ii) ensure a more accurate system design, and, and (iii) clarify the FMS design specifications.

Hughes and Hegland (1983) advocate that the cooperation and the exchange of business planning information between vendor and user are crucial for establishing a long-term partnership focused on productivity. A key factor in successful FMS installation and implementation is the degree of commitment from the potential user, which is not limited to large corporations with vast financial resources. Goldhar (1984) explains that introducing an FMS into an organisation has strategic implications for both ‘economies of scale’ and ‘economies of scope’. An FMS can be installed incrementally through the employment of machines or the utilisation of manufacturing cells.

Generally, FMS implementation has been reported to lead to improved quality, reduced in labour and inventory costs, and increased market responsiveness (Kaighobadi and Venkatest, 1994).

A cooperative and close relationship with suppliers has been identified as a main factor in successful FMS implementation. Dallas (1984) confirms that FMS can succeed if (i) it functions in the right economic context, (ii) the company’s organisational structure is redesigned to accommodate FMS requirements, (iii) there is closer cooperation between vendors and users of the technology, and (iv) management understands the new operational rules, (v) there is a managerial mind-set reorientation regarding performance evaluation, capital rationing criteria, and human resources management (Klahorst, 1981; Kaighobadi and Venkatest, 1994).

Challenges in Installation, Implementation and Integration of FMSs

Kaighobadi and Venkatest (1994) highlight that an FMS poses several implementation problems, particularly in integration, which can be classified as (i) technical problems, and (ii) managerial problems. Technical problems arise from the technological complexity and the numerous technical analytical decisions required. Managerial resistance to change is the primary reason for managerial problems and adds to the complexity of FMSs implementation.

Technical Problems

The economical functioning of an FMS depends on the effectiveness of its design, control and monitoring of FMS. Since FMS-related problems cross the boundaries of manufacturing, industrial, computer and electrical engineering, as well as computer science and operations management, understanding them requires a specific examination of each issue. To address these problems in FMSs, the following approach is recommended: (i) consider all functional subsystems constituting an FMS and understand the prominence of each, (ii) address problems related to each subsystem, and (iii) analyse the impact of each subsystem on the system as a whole. The important functional subsystems present in an FMS include (i) CNC/DNC machine tool technology, (ii) tool management, (iii) automated material handling, and (iv) a communication network to integrate all elements, including real-time control (Kaighobadi and Venkatest, 1994).

Managerial Problems

According to Goldhar (1984) the National Bureau of Standards addressed three main problem areas in FMSs: (i) simplifying the control architecture, (ii) resolving difficulties in configuring FMSs, and (iii) ensuring consistent product quality within these systems.

Kaighobadi and Venkatest (1994) summarise the main managerial barriers of FMS, which are concentrated in a few major areas: (i) lack of top management commitment and support, (ii) inadequate personal training and education, (iii) improper evaluation of the situation justifying FMS installation, (iv) lack of long-term and committed relationship with vendors, (v) lack of total commitment to the installation and implementation of the FMS, and (vi) misconceptions about FMSs, such as it being suitable only which FMS being good only for large companies and only applicable to large scale production, or FMS being the panacea for all of a system’s problems).

Harvey (1984) echoes this, starting that the major barriers to the efficient factory are financial, human, institutional, communication, education and technological. He proposes a procedure for building a supportive organisational climate: (i) educate senior management, (ii) set goals and develop strategies, (iii) establish a corporate-wide culture, (iv) develop a unified communication structure. This would enable management to justify financial investment in the factory of the future.

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The Resolutions for the Challenges of FMSs

Future FMS research should aim to develop integrated systems that address both the technical and managerial problems discussed earlier. Such integration could help to integrate the efforts of both technical and managerial personnel for full FMS realisation (Kaighobadi and Venkatest, 1994).

In this section, the literature discusses (i) the FMS definitions, (ii) the impetus for change from conventional systems to FMSs, (iii) the installation, implementation and integration of FMSs, and (iv) associated challenges of FMS, categorising the challenges into technical and managerial. Hughes and Hegland (1983) suggest major advances in FMSs, including: (i) the application of automated fixturing and holding devices on numerically controlled machines, (ii) reliable and practical sensing strategies for implementing adaptive control, (iii) the extension of FMSs to the machine tool industry, (iv) in-process adaptive control of surface roughness in machining, (v) non-contact high-speed on-line inspection systems with closed loop feedback, and (v) increased application of diagnostic components in FMSs.

METHOD

This research adhered to the strict confidentiality rules and regulations set by the participating companies and respondents. A qualitative approach was employed to gain contextual insights. Primary data were collected through semi-structured interviews with eight factory managers from eight different E&E manufacturing companies in Penang that have implemented FMS. The companies represent four categories (i) Factory Manager 1 and 2: Multinational Corporations (MNCs), (ii) Factory Manager 3 and 4: General Contractors, (iii) Factory Manager 5 and 6: Large Malaysian Companies, (iv) Factory Manager 7 and 8: Medium-sized Malaysian Companies. To protect identities, all company names remain anonymous, and all respondents are referred to as 'factory managers'. The use of secondary data was prohibited, as it could potentially reveal company identities. Courtesy factory visits enable observational data, which enriched the study. However, no photographs or videos were permitted to maintain confidentiality. The collected data were analysed using thematic analysis with priori codes to identify prevalent patterns and themes derived from existing theory and matched with the primary data.

RESULTS AND DISCUSSION

The experiences gained through the installation, implementation and integration of FMS are shared by eight respondents from the eight different Penang E&E companies.

Definitions of FMSs From Eight Industrial Practitioners

During a production line visit at Company A (an MNC), Factory Manager 1 explained FMS as a production method designed to adapt to changes in product type and quantity. He described an FMS of different workstations, each working on different products. These stations consist of computer-controlled machines working simultaneously, interconnected by a conveyor system that transfer items from one workstation to another.

Factory Manager 1 and 2 (from different MNCs) jointly emphasized that, FMS is defined by its capability to handle different jobs on different machines at various working stations, which collectively form a single product or part. Furthermore, they explained that FMSs enable simultaneous processing along different paths at various workstations. This allows production design and quantities to be adjusted according to customer demand, facilitating a quick response to market changes.

As explained by Factory Manager 3 and 4 (from general contractors), and Factory Manager 5 and 6 (from large Malaysian companies) during site visits; an FMS consists of four common components: (i) workstations, (ii) an automated material handling system, (iii) human resources, and (iv) a computer control system.

The workstations are systematic machining station operated by CNC machines. The automated handling system, which may use conveyors or rail systems, transports materials between workstations, handles a variety of work configurations, and facilitates loading and unloading. Human resources are responsible for programming, operational planning, tool changing, and system maintenance; all of which require complex decision-making.

Finally, the computer control system functions as the central interface, integrating the operator with the FMS components to manage workstations, material handling, storage, production traffic, system monitoring, and reporting.

Impetus for Change from Conventional Manufacturing Systems to FMSs: The Experiences of Eight Penang's E&E Companies

According to all factory managers interviewed, FMSs were introduced to most Penang E&E companies in the 1980s. This shift was driven by intense global market competition that demand more efficient system capable of operating 24 hours with minimal human intervention. FMS in Malaysia occurred nearly a decade after FMS was first identified in developed countries in the early 1970s.

The 1980s in Malaysia were marked by intense competition in the E&E industry, fueled by the influx and the growth of foreign multinational corporations (MNCs) and the Malaysian government efforts to attract foreign direct investment. As noted by by Okamoto (1994), this competition environment involved foreign companies establishing manufacturing based and assembly operations in Malaysia (particularly in Penang), the local companies vying to supply them, and growing internal competition from local managers and engineers for more advanced responsibilities in design and manufacturing. This period represented a critical transition from low-tech assembly to sophisticated manufacturing, driven by government policies and global demand for electronics.

Factory Manager 5 and 6 commented "Companies use FMS due to advantages, such as reducing manufacturing costs, increasing productivity, and improving machine efficiency." All Factory Managers agreed that FMS delivers benefits, including: (i) maximised machine utilisation as the fully automated system enables 24 hours operations, (ii) reduced the factory workspace, (iii) greater responsiveness to both predictable and unpredictable changes, (iv) reduced inventory requirement through efficient stock management, (v) fewer machine required for production since one machine can perform multiple processes, and (vi) shorter manufacturing lead time.

Factory Manager 7 and 8 (from Medium-sized Malaysian companies) further elaborated that FMS is capable to process different product parts in a mixed-model mode. The FMS is readily flexible to accommodate changes in production schedules and quantities, as well as can recover fully from equipment malfunctions to prevent production disruptions. Consequently, FMS introduces a new operational pathway into existing conventional manufacturing systems.

Installation, Implementation and Integration of FMSs in Eight Penang's E&E Companies

As established in the literature review, an FMS integrates multiple machine centres and material-handling systems under a hierarchical computer control structure.

Observation during a production line visit at Company B (an MNC) revealed different types of FMS. As Factory Manager 2 explained, there are three types of FMS which is categorised by the number of machines in the system:

(i) a single machine cell, controlled by one CNC with automated storage or handling system, (ii) a flexible manufacturing cell, containing 2-3 processing workstation controlled by several CNCs, and (iii) a full FMS containing four or more processing workstations controlled by multiple CNCs. This full FMS is connected to a central pastoral system that manages loading and unloading paths to and from storage, which it is designed to operate in batch mode, flexible mode or both. Generally, systems with more machines achieve faster product cycle time and higher total outputs.

Despite Company B's high competency in FMS, Factory Manager 2 emphasised "We are designing a facility to achieve what the clients want. However, it is not just the facility we are designing. We have to tackle both facility and manufacturing process together in an integrated fashion".

The need for flexibility was echoed by suppliers. Factory Manager 3 and 4 from general contractor companies, stated "Flexibility in manufacturing is needed since we cannot afford to have every specific machinery equipped within the production. We have to fine-tune the machines that we have, to produce similar products in the pipelines".

Factory Manager 3 elaborated on client expectations: "The first questions we received from clients is 'What kind of flexibility facilities do you have in your production?' We have to understand if the clients are looking at our ability in terms of economies of scale or economies of scopes while producing more variations." Factory Manager 4 added "These products will change gradually based on technological feasibility and market demand. The conversion process needs to be planned up front. We must understand the project goals before we initiate the project."

Challenges in Installation, Implementation and Integration of FMSs: The Experiences of Eight Penang's E&E Companies

Kaighobadi and Venkatest (1994) identified two common challenges in FMS implementation: (i) technical problems, and (ii) managerial problems. While FMS offers advantages in production size and process continuity, allowing all manufacturable products to run on the system, the findings from eight Penang's E&E companies reveal a nuanced picture. Among the companies studied, there was no significant evidence of managerial resistance to change, suggesting that managerial problems are not a primary barrier to FMS implementation in this context.

However, significant technical and financial challenges persist. Factory Manager 5 explained that, FMS entails high costs, complexity, high maintenance costs and a need for highly skilled worker. The high initial investment covers machinery, equipment, software and setup. The process involves complex planning, design and integration, leading to a time-consuming implementation that can involve trial and error. "Many times, a failure in one part can cause a shutdown across the entire production. Every time the machinery has to be reprogrammed to accommodate a minor product change in specs and features for the FMS to install," Factory Manager 5 noted.

Agreeing with high startup costs, expensive training, and lengthy development time, Factory Manager 6 justified the hesitation many companies feel, "We find a lot of companies look at risk assessment, thinking about how much a company willing to accept from a risk standpoint. In reality, many companies are not willing to accept a lot of risks because they do not want to operate outside of their established parameters."

Factory Manager 7 highlighted the challenges in a complex environment: "If you are in a multi-phase and multi-product kind of scenario, you have to pay a lot of attention to changeover. For a lot of organisations, this becomes a big challenge if you want to minimise risks while maximise the efficiency." Factory Manager 8 emphasised the complexities of such environment "Under such scenario, we can expect either higher traffic in the production lines or a lot of complex interactions. There is a risk of product cross-contamination, a critical concern when an FMS produces multiple products."

The Resolution for the Challenges of FMSs by Eight Penang's E&E Companies

As advocated by Kaighobadi and Venkatest, (1994), future FMS research should aim to develop integrated systems addressing both technical problems and managerial problems.

From the perspective of E&E general contractors, Factory Manager 3 hypothesised "If you have high traffic in certain lines/aisles, you have to cautious about the manufacturing time and where that traffic will force you to redesign your facility to avoid pinch points that will slow you down." Factory Manager 4 added, "Time is money in these facilities, so they have to operate highly efficient using FM techniques. Whenever you have bottlenecks or places where things slow down, there is a possibility of product quality issues."

From the angle of large Malaysian E&E companies, Factor Manager 5 explained that, FMS today centers around scale of operations. He noted that over the past few years, facility assets have shrunk while throughput capability has increased due to advances in Industry 4.0 technology, where scale is a major factor. He stated: "Agility focuses on flexibility and speed of adaptation to changing market demands. The objective is to deliver quality customised products with shorter lead times while sustaining cost competitiveness." Factory Manager 6 highlighted that when designing an FMS facility, companies must address operational risk beforehand, whether driven by product technology or the process technology.

Regarding the avoidance of product cross-contamination, Factory Manager 8 recommended two strategies "One area often not addressed initially is the whole idea of a segregation strategy, which goes beyond the attributes of the facility or equipment design. Firstly, the ability to define and validate system closure are important to ensure product protection. Secondly, we can frequently model the manufacturing process to maintain efficiency during high traffic and complex interactions. This is to ensure the manufacturing process can eliminate the possibility of product cross-contamination."

Elaborating on the segregation strategy for multi-phase and multi-product scenarios, Factory Manager 7 explained "When running multiple operations with FMS, the key is managing the operational interface points. When running on compatible automation platforms across different process elements within set of boundaries. It is about integrating these interface points from the beginning and ensuring proper segregation takes place to avoid product cross-contamination."

While high initial and maintenance costs for FMS are unavoidable, the issue of a highly skilled workforce was also discussed. Factory Manager 1, 2 and 5 agreed that, targeted training such as start-up and maintenance training is essential to bring operators to a skill level where they can effectively manage the FMS.

However, Factory Manager 1 and 2 from MNC described a different approach to this human resource challenge. Their companies have implemented AI-powered automation systems capable of resolving capability failover. If one machine breaks down, the system can adapt another machine to take over the task preventing downtime. Visits to Company A and Company B, revealed robot-centered FMS layouts, using one or more robot as material handler. "We use robotics in our production, including fixed robotics, SCARA robots and quattro-delta kinematics. We integrate these collaborative robots to minimise operators' reliance," said Factory Manager 1.

Factory Manager 2 added, "Everything here is controlled by a fully automation platform. We are looking to future developments to extend this platform, which will be a game-changer for our competitiveness," In conclusion, the most technologically advanced MNCs possess the capability to implement FMS fully. For these companies, while costs are significant, they are not barriers to implementing the most advanced systems, which leverage IoT, robotic and cyber-connectivity.

CONCLUSION

This research provides an understanding of FMS practices in Penang E&E companies across four major categories (MNCs, general contractors, the large Malaysian companies and the medium Malaysian companies). The findings suggest that successful FM implementation requires a holistic strategy that addresses both managerial problems and technical problems, particularly those related to finance and human resources.

Two key points emerge: Firstly, while all eight E&E companies are implementing FMS, many of them, particularly the general contractors and medium Malaysian companies do not have a full-blown, academic-style FMS. Their utilisation of automation, CNC, robotics, and digital integration is heavily dependent on their business nature and their role in the upstream or downstream of the national/international E&E industry.

Secondly, different company categories face different challenges and risks. The MNCs, with their advanced technology, are best positioned to implement FMS and are further extending them by leveraging Industry 4.0. Meanwhile, the large Malaysian companies, with their local technological competency and market share, performed better than general contractors and medium-sized Malaysian companies. For the latter two groups, the key challenges remain high costs, complexity, high maintenance and the need for highly skilled workers, all exacerbated by their ore limited resources.

In conclusion, the research demonstrates that FMS implementation necessitates a holistic strategy that addressing not only technical aspects but also human resource development. This study offers valuable, ground-level insights for industry practitioners and provides information for potential company decision-makers to create targeted support programs, ultimately aiming to bolster the competitiveness of eight Penang's E&E companies through FMS.

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REFERENCES

1. Blumenthal, M., & Dray, J. (1985). The automated factory: Vision and reality. *Technology Review*, *88*(1), 28–37.
2. Buffa, E. S. (1984). *Meeting the competitive challenge: Manufacturing strategies for US companies*. Richard D. Irwin.
3. Dallas, D. B. (1984). The impact of FMS. *Production*, *9*(10), 33–38.
4. Darrow, W. P. (1987). International comparison of flexible manufacturing system technology. *Interfaces*, *17*(6), 88. https://doi.org/10.1287/inte.17.6.88
5. Davis, W. J., Jackson, R. H. F., & Jones, A. T. (1989). Real time optimization in the automated manufacturing research facility. In J. A. White & I. W. Pence (Eds.), *Progress in material handling and logistics* (pp. 113-127). Springer Verlag.
6. Goldhar, J. D. (1984). What flexible automation means to your business. *Modern Material Handling*, *39*, 63–65.
7. Gupta, D., & Buzacott, J. A. (1989). A framework for understanding flexibility of manufacturing systems. *Journal of Manufacturing Systems*, *8*(2), 89–97. https://doi.org/10.1016/0278-6125(89)90025-5
8. Harvey, R. E. (1984). Factory 2000. *Iron Age*, *227*, 72–76.
9. Hughes, T., & Hegland, D. (1983). Flexible manufacturing: The way to the winner's circle. *Production Engineering*, *30*(9), 55.
10. Invest Penang. (2025). *Electrical & electronics*. Retrieved February 20, 2025, from https://investpenang.gov.my/electrical-electronics/
11. Kaighobadi, M., & Venkatesh, K. (1994). Flexible manufacturing systems: An overview. *International Journal of Operations & Production Management*, *14*(4), 26–49. https://doi.org/10.1108/01443579410056026
12. Klahorst, T. H. (1981). Flexible manufacturing systems: Combining elements to lower costs, add flexibility. *Industrial Engineering*, *13*(11), 112–117.
13. Okamoto, Y. (1994). Impact of trade and FDI liberalisation policies on the Malaysian economy. *The Developing Economies*, *32*(4), 460–474. https://doi.org/10.1111/j.1746-1049.1994.tb01050.x
14. Ranky, P. (1983). *The design and operation of FMS: Flexible manufacturing systems*. IFS Publications.
15. Salomon, D. P., & Beigel, J. E. (1984). Assessing economic attractiveness of FMS applications in small-batch manufacturing. *Industrial Engineering*, *16*(6), 88–96.
16. Yilmaz, O. S., & Davis, R. P. (1987). Flexible manufacturing systems: Characteristics and assessment. *Engineering Management*, *4*(4), 209–212.