

A Universal Scheduling Application for Product Portfolios

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Abstract

This study investigates work order scheduling for product portfolios at the enterprise level by extending the traditional $\alpha|\beta|\gamma$ scheduling framework to support production–marketing coordination. While the triplet structure is widely applied to single-system scheduling, its role in portfolio-level decision-making remains limited, particularly when allocating multiple products across diverse manufacturing environments. To address this gap, a universal scheduling model is proposed to integrate appropriate scheduling criteria into enterprise-wide planning. The model accommodates various machine environments in the α field, including single machine, parallel machines, flow shop, flexible flow shop, job shop, flexible job shop, and open shop systems, ensuring high flexibility and general applicability. In addition, a Python-based application is developed to convert work order data from Excel into the proposed model, enabling systematic scheduling and analysis. The approach supports the evaluation of production line efficiency, prioritization of product portfolios, and generation of feasible or near-optimal schedules. This study provides a scalable and adaptable decision-support tool that enhances coordination between production and marketing in complex manufacturing systems.

Keywords

Scheduling, ERP, MRP, Product Portfolios

1. Introduction

When the manufacturing environment is involved, converting a customer order into a work order indicates the beginning of manufacturing, building, or engineering the products that the customer has requested. A production and sales analysis and coordination requires agreement between production and sales parties through negotiation or experience judgment regarding what to produce, how much to produce, and when to deliver (i.e., product portfolios). The input of a production and sales meeting, theoretically, is customer orders, and its output should be work orders, or at least rough work orders (i.e., outcomes of rough cut capacity planning).

Rough Cut Capacity Planning (RCCP) is an essential method in production management that provides a macro-level evaluation of resource feasibility by aggregating production capacity and demand. However, traditional RCCP relies on simplified assumptions regarding resource independence and fixed lead times, which may lead to inaccurate planning results (Orlicky, 1975; Wight, 1984; Vollmann et al., 2005). In practice, manufacturing systems exhibit complex interdependencies among machines and processes, which are not fully captured in classical MRP-based approaches (Hopp and Spearman, 2011). Moreover, the Master Production Schedule (MPS), as a key output of MRP II systems, often depends on historical or estimated lead times, which may not reflect real-time production conditions (Segerstedt, 2006). This limitation motivates the need for integrating advanced scheduling models into RCCP to improve capacity estimation and coordination between production and marketing.

A major aspect to overcoming these limitations is implementing a production scheduling algorithm. Traditional algorithms used for scheduling production are typically developed for specific production processes or machine types. They may be effective for specific environments; however, they typically lack the ability to change based on shifting configurations or complex interaction between machines and therefore can produce scheduling decisions that are unfavorable, areas of congestion, and incorrect capacity forecasts.

In contrast, a universal production scheduling algorithm is designed to be adaptable across a wide range of production environments, handling various types of machines, production flows, and process interdependencies. By integrating a universal scheduling model, planners can significantly enhance RCCP's effectiveness in three key areas:

- **Accurate Capacity Representation:** It provides a more realistic view of production capacity by dynamically adjusting schedules based on detailed interactions and dependencies between machines.
- **Flexibility and Adaptability:** It can quickly recalculate schedules based on new constraints, machine setups, or shifting demands, ensuring that the production plan remains feasible in modern, dynamic environments.
- **Optimized Resource Utilization:** It dynamically allocates tasks based on current availability, balancing workloads across machines to minimize idle time and avoid overloading.

Therefore, the integration of a universal production scheduling algorithm represents a significant improvement over methods relying on traditional algorithms. For RCCP to fully realize its potential in modern, complex manufacturing systems, developing and implementing such a scalable and adaptable scheduling framework is essential.

2. Literature Review

According to ERP (Enterprise Resource Planning) and MRP II (Manufacturing Resource Planning), the production plan scheme (PPS) is a guideline/goal for the sales department, and the master production schedule (MPS) is a way of coordinating the results of the production and sales meeting. MPS refers to the planning stage of generating rough work orders of end items, because it indicates what to produce, how much to produce, and when to deliver (Segerstedt, 2006).

Figure 1 illustrates the planning and scheduling procedures for work orders. It is also known as closed-loop MRP. The role of MRP at this stage is determined by whether MPS is reasonable and feasible. In general, one of the main factors that determine whether a MPS is reasonable and feasible is that the manufacturing lead time of every end item is an estimate based on experience when constructing an MPS, and since the manufacturing lead time of these end items will be also affected by "the combination of which end items", so the setting of the manufacturing lead time may be too strict, so that after the MRP calculation it is discovered that it is not feasible; or it may be too loose, resulting in decreased sales opportunities.

Traditional MRP systems assume deterministic and fixed lead times regardless of system load or product mix, which limits their applicability in dynamic manufacturing environments (Orlicky, 1975; Vollmann et al., 2005). Furthermore, MRP does not explicitly consider capacity constraints, often generating infeasible production plans (Wight, 1984). These limitations have led to the development of extended planning frameworks and hybrid approaches that integrate scheduling into planning processes (Hopp and Spearman, 2011).

The major problem with MRP systems is the requirement that the planner specify how long it will take a factory to make an end item from its component parts (assuming they are all available), and the system design also assumes that this manufacturing lead time will be the same each time the item is made, without regard to quantity being made, or other items being made simultaneously in the factory. The other major drawback of MRP is that it does not take capacity into account in its calculations. This means it will give results that are impossible to implement due to resource capacity constraints. In such circumstances, the achievable MPS is usually a loose schedule, and thus, it is necessary to undertake a larger-scale work order mathematical scheduling model in the shop floor. There is a scalability issue with a mathematical scheduling model, and hence a need for meta-heuristic algorithms to resolve a scheduling problem in a reasonable amount of time, even though one feasible solution has been obtained (Figure 1).

Production scheduling problems, especially in job shop and flow shop environments, are well known to be NP-hard (Garey et al., 1976). As a result, a large body of research has focused on heuristic and meta-heuristic approaches, such as genetic algorithms, tabu search, and evolutionary methods, to obtain near-optimal solutions within reasonable computational time (Jain and Meeran, 1999; Ruiz and Maroto, 2005).

More recently, studies have extended these approaches to hybrid and flexible shop environments, including open shop and flexible job shop systems, further increasing model generality and applicability (Fan et al., 2018; Ahmadian et al., 2021).

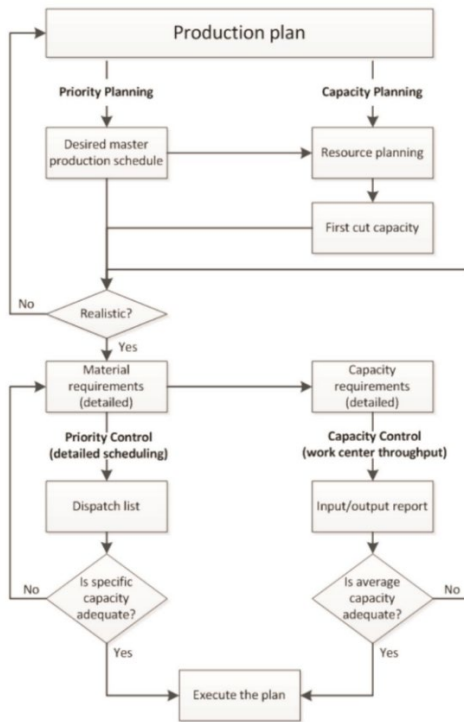


Figure 1. Closed-loop MRP

Work order planning and scheduling involves a number of variables: (1) manufacturing lead time, (2) production lots, (3) routing, (4) processing time, (5) combination of end items, and (6) capacity of resources. There was a lack of computational capability and tools in the past, which allowed these variables to interact with one another (as shown in Figure 1) by using some estimated factors, leading to a chicken and egg dead knot problem. However, this is largely handled by MRP II. MRP II is not a proprietary software system and therefore can be implemented in a variety of ways.

This paper presents a novel method for utilizing MPS, Product Portfolio Requirements Planning (a variation of MRP), and Scheduling (as shown in Figure 2) that utilizes a powerful computational algorithm and we call it the universal scheduling model. The methodology that we propose can be viewed as an extension of MRP II.

3. Theoretical Framework

For scheduling work orders, we generally refer to the triplet framework ($\alpha|\beta|\gamma$) developed by (Pinedo, 2012). The α field represents the machine environment and contains just one entry; the β field represents work order and/or machine constraints and may contain no entry at all, a single entry, or multiple entries; and the γ field represents scheduling objectives to be optimized and often contains a single entry or a mixed single entry. However, what $\alpha|\beta|\gamma$ triplet is when we plan and schedule work orders for a set of end products? Figure 2 illustrates three manufacturing bills of materials (M-BOMs) for three end products (e.g., end product A, X, S Figure 2). M-BOMs contain several manufacturing components (e.g., component C, E, Y in Figure 2) and several purchasing components (e.g., component B, D, F, G, W, M, N in Figure 2). As a manufacturing part/component is normally assigned to a production line (or production unit), a work order is planned and assigned to the production line. The α field indicating a machine environment means a production line environment. If multiple work orders are assigned to a production line (e.g., production line 1, 2 in Figure 2), it is important to schedule the start and finish times of each work order (or at least a

sequence of those work orders) on each machine on the line. Therefore, the γ field represents the scheduling objective of a production line, and the β field represents the constraints within a production line.

The $\alpha|\beta|\gamma$ classification framework provides a standard representation for scheduling problems (Pinedo, 2012). However, most existing models are designed for specific machine environments and lack the flexibility to handle multiple production configurations simultaneously.

According to scheduling theory, more generalized shop models, such as flexible job shop and open shop, can encompass simpler environments including single machine and flow shop systems (Fan et al., 2018; Ahmadian et al., 2021). Using the theoretical framework of scheduling, we conclude that a universal scheduling model must be equipped with the following four core capabilities to overcome practical manufacturing challenges:

- **Work Order Sequencing:** Handling the selection of optimal work order sequences for each machine.
- **Cycling Loop Resolution:** Defining and effectively solving cycling loop issues within the production routing.
- **Parallel Machine Allocation:** Managing the parallel machine selection problem for each work order at specific points in time.
- **Non-equivalent Machine Computation:** Performing accurate computations for production rates across unequal parallel machines (Figure 2).

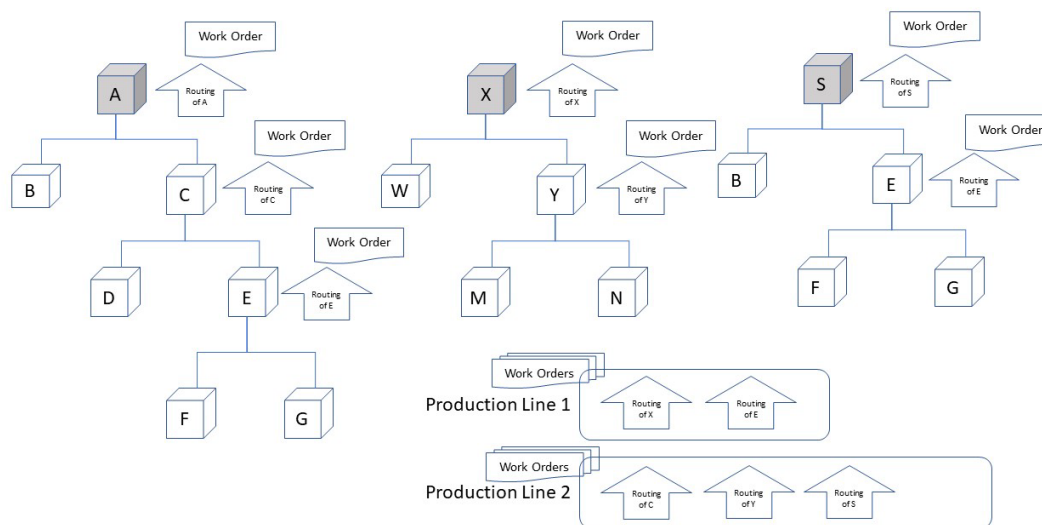


Figure 2. M-BOMs of 3 End Products and Production Lines (Shiau et al., 2023)

One of the reasons MPS uses historic manufacturing lead times is that an end item with a multi-level M-BOM is typically assembled on more than one production line. Consequently, to schedule detailed work orders of an end item, it requires several scheduling models (one for each production line). This creates the requirement for developing a universal mathematical scheduling model that can yield the optimal scheduling solutions for each production line.

By using the universal scheduling model, we can calculate manufacturing lead times of a set of end items and generate load-dependent lead times (LDLT) for MPS. This will result in a better MPS for MRP, which will in turn generate higher performing work orders. Additionally, we developed several performance indexes to define time windows for MRP calculations in the proposed methodology. We called this time-window-limited approach to MRP Product Portfolio Requirements Planning (PPRP).

By utilizing PPRP, the scalability of our proposed universal scheduling model is dramatically reduced. In this way, the calculation time of work order planning and scheduling can be made in a reasonable amount of time. The outcome

of our proposed methodology is a set of time window limited detail work orders. Thus, this methodology could serve as a decision support tool for production and sales coordination meetings.

The interaction among multiple end items in a product portfolio significantly affects manufacturing lead times and system performance. Traditional approaches often overlook this interaction, leading to inaccurate planning outcomes. Prior research has explored integrated production–inventory models and portfolio-level decision-making to address such issues (Graves, 1986; Federgruen and Zipkin, 1986; Silver et al., 1998).

Recent studies have further emphasized the importance of scheduling product portfolios and developing dispatching rules that consider interdependencies among jobs (Shiau et al., 2023). These findings highlight the need for load-dependent lead time (LDLT) estimation within integrated scheduling frameworks.

It was suggested by (Ahmadian et al., 2021) to construct a complexity hierarchy diagram of a scheduling problem model (Figure 3). According to this hierarchy diagram, a parallel machine (Pm) scheduling model is capable of solving the scheduling problem of a single machine with the number of machines as one. In the same way, a model that can solve the scheduling problem of flow shop (F_m) can also be used to solve the scheduling problem of a single machine. Scheduling models that are able to solve flexible job shop problems (FJ_c) can also be used to solve job shop problems (J_m), flow shop problems (F_m), and single machine scheduling problems.

The literature describes a scheduling model for flexible open shop (FO_c), which is in principle applicable to the scheduling of non-equivalent parallel machines (R_m), flexible job shop (FJ_c), job shop (J_m), open shop (Om) and other schedules (Fan et al., 2018; Ahmadian et al., 2021). Thus, we can refer to it as a universal scheduling model in Figure 3.

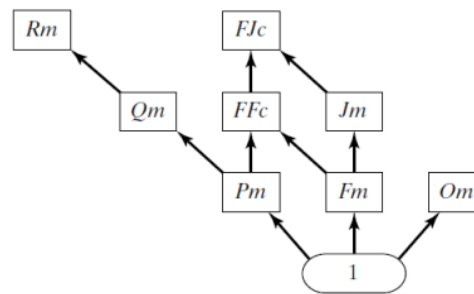


Figure 3. Hierarchical Diagram of Machine Environment (α)

Using the theoretical framework of scheduling, we conclude that a universal scheduling model must be able to handle the following four challenges:

1. It is capable of handling the selection of work order sequences for each machine.
2. It is capable of defining and solving a cycling loop issues.
3. It is capable of handling the parallel machine selection problem for each work order at a specific point in time.
4. It is capable of performing computations at the rate of unequal parallel machines.

4. The Universal Scheduling Application

The primary objective of this study is to identify and integrate appropriate scheduling criteria into enterprise-wide production and marketing coordination mechanisms, so as to ensure that work orders within a product portfolio can be scheduled in a feasible and, when possible, optimal manner. To achieve this objective, the study first develops a universal scheduling model that serves as the core theoretical framework, thereby fulfilling the fundamental research purpose. From a practical perspective, Python programming is employed as a data processing tool to read, transform, and systematically convert work order information stored in Excel format into the proposed universal scheduling model.

From an implementation perspective, enterprise systems such as ERP platforms play a crucial role in integrating planning and execution (Monk and Wagner, 2012). Modern ERP solutions increasingly incorporate data-driven tools and flexible architectures to support advanced scheduling functions. In this study, Python is adopted as the core development tool due to its powerful data processing capabilities and extensive ecosystem for scientific computing (Van Rossum and Drake, 2009; McKinney, 2010). The integration of spreadsheet-based data with computational models enables practical deployment of the proposed scheduling framework in real-world environments.

The application system developed in this study takes Excel worksheets (as illustrated in Figure 4) as the primary input source. After data conversion and model computation, the system automatically generates a detailed processing timetable for each job across different machines.

Process_Sheet	Equipment	Processing Time	Machine_Group	MachineID	Processing Time	JOBA	JOBB	JOBC
2								
201-1	CB27,CB28	0.75	301-1	CB27,CB28	0.75/0.75	1	1	1
202-1-1	YF04	1.4						
202-1-2-1	YC03,YC04	0.24						
202-1-2-2	TA05,TA07	1.20						
203-3-3	YB04	1						
203-3-4	PA01,PA03	0.20						
202-1-3-2	CB26	0.5						
202-1-4	HB05	2.4						
202-1-5	CB15	0.5						
202-2-1	YC03,YC04	0.24	302-1-3-1	YC03,YC04	0.24/0.24	1	1	1
202-2-2	TA05,TA07	1.20						
202-2-3	YB04	1						
202-4-1	PA01,PA03	0.20	302-1-3-1	PA01,PA03	0.20/0.20	1	1	1
202-4-2	CB26	0.5	302-1-3-2	CB26	0.5	1	1	1
202-5	CB26, CB27	2.02-5		CB26, CB27, CB28, CB29, CB30, CB31	0.00-2.02-5	1	1	1

Figure 4. The Excel Sheet for Work Orders of Product Portfolios

The resulting scheduling solution is visualized in the form of a Gantt chart (as shown in Figure 5), where the horizontal axis represents machines and the vertical axis denotes processing time in hours. This visualization not only facilitates intuitive interpretation of scheduling results but also enhances managerial decision-making by clearly illustrating machine utilization and job sequencing.

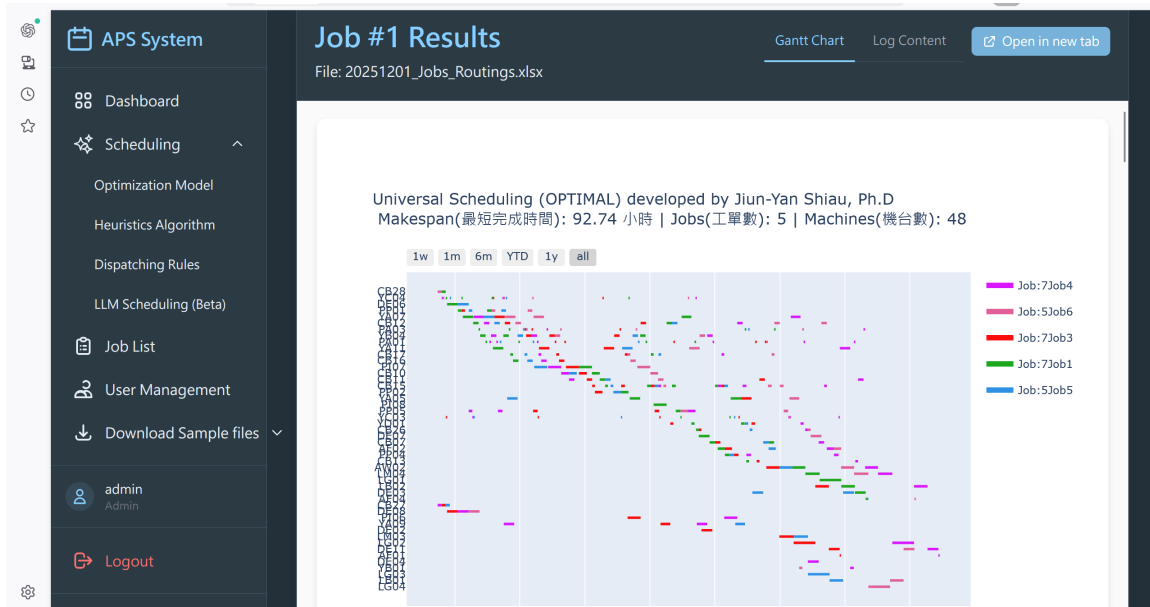


Figure 5. The Application with a Gantt Chart Illustrating the Scheduling Problem

Furthermore, the machine environment (α field) of the proposed model is highly flexible and extensible. It is capable of representing a wide range of production configurations, including single machine systems, parallel machines, flow shops, flexible flow shops, job shops, flexible job shops, and even open shop environments. Owing to this

comprehensive modeling capability, the proposed framework possesses strong generality and adaptability, thereby justifying its designation as a universal scheduling model, as emphasized in the title of this study.

5. Conclusion

A universal scheduling solution is developed and implemented in this study. This study is focused on work order scheduling for product portfolios at the enterprise level. A universal scheduling model extending the traditional $\alpha | \beta | \gamma$ (alpha, beta, gamma) work order scheduling framework provides a way to overcome the limitations associated with single-system scheduling. By providing a complete scheduling solution at the portfolio level, the universal scheduling model allows for effective decision-making for product portfolios at the enterprise level.

This universal scheduling application also demonstrates strong generality and flexibility as it applies to different machine arrangements in the α field including single machine, parallel machine, flow shop, flexible job shop, and open shop systems. To ensure that there are practical applications of this universal scheduling model and to bridge the gap between the theoretical and practical application, a Python application was developed which runs in a systematic manner and converts work order data from standard, typical Excel spreadsheets into the proposed computational model of this universal scheduling system. The application also automates the creation of detailed processing timetables for work orders and generates Gantt charts for visual presentation of the results, thus allowing for intuitive understanding of machine utilization and work order sequence.

Overall, the universal scheduling application is a scalable and flexible decision-support tool that allows for comprehensive assessment of production line effectiveness, prioritization of product line portfolios, and development of feasible and near-optimal work order sequencing. Incorporating the advanced scheduling criteria into an enterprise-wide planning process results in significantly improved communications between the production and marketing functions in complex manufacturing environments, thereby producing reliable estimates of capacity and optimal resource utilization for manufactured products.

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References

- Ahmadian, M. M., et al., "Four decades of research on the open-shop scheduling problem to minimize the makespan," *European Journal of Operational Research*, 295(2), pp. 399-426. 2021,
- Fan, K., et al., "Review and classification of hybrid shop scheduling," *Production Engineering*, 12(5), pp. 597-609, 2018.
- Federgruen, A., and Zipkin, P., "An inventory model with limited production capacity and uncertain demands II," *Mathematics of Operations Research*, 11(2), pp. 208-215, 1986.
- Garey, M. R., Johnson, D. S., and Sethi, R., "The complexity of flowshop and jobshop scheduling," *Mathematics of Operations Research*, 1(2), pp. 117-129, 1976.
- Graves, S. C., "A tactical planning model for a job shop," *Operations Research*, 34(4), , pp. 522-533. 1986
- Hopp, W. J., and Spearman, M. L., "Factory Physics," 3rd ed., Waveland Press, 2011.
- Jain, A. S., and Meeran, S., "Deterministic job-shop scheduling: Past, present and future," *European Journal of Operational Research*, 113(2), pp. 390-434, 1999.
- McKinney, W., "Data structures for statistical computing in Python," *Proceedings of the 9th Python in Science Conference*, pp. 51-56, 2010.
- Monk, E., and Wagner, B., "Concepts in Enterprise Resource Planning," 4th ed., Course Technology Cengage Learning, 2012.
- Orlicky, J., "Material Requirements Planning," *McGraw-Hill*, 1975.
- Pinedo, M. L., "Scheduling: Theory, Algorithms, and Systems," Springer New York, 2012.
- Ruiz, R., and Maroto, C., "A comprehensive review and evaluation of permutation flowshop heuristics," *European Journal of Operational Research*, 165(2), pp. 479-494, 2005.
- Segerstedt, A., "Master Production Scheduling and a comparison of Material Requirements Planning and cover-time planning," *International Journal of Production Research*, 44(18-19), pp. 3585-3606, 2006.
- Shiau, J.-Y., et al., "Dispatching Rules for Scheduling Product Portfolios," *International Journal of Industrial Engineering: Theory, Applications and Practice*, 30(6), 2023.

- Silver, E. A., Pyke, D. F., and Peterson, R., "Inventory Management and Production Planning and Scheduling," 3rd ed., Wiley, 1998.
- Van Rossum, G., and Drake, F. L., "Python 3 Reference Manual," Python Software Foundation, 2009.
- Vollmann, T. E., Berry, W. L., Whybark, D. C., and Jacobs, F. R., "Manufacturing Planning and Control Systems for Supply Chain Management," 5th ed., McGraw-Hill, 2005.
- Wight, O. W., "Production and Inventory Management in the Computer Age," Van Nostrand Reinhold, 1984.

Biography

Jiun-Yan Shiau is a Professor in the Department of Logistics Management at National Kaohsiung University of Science and Technology (NKUST), Taiwan. He currently teaches courses in computer programming, database systems, big data analytics, enterprise resource planning (ERP), and electronic commerce. In addition to his academic appointment, he also serves as the Associate Dean of the College of Management at NKUST, contributing to both academic leadership and administrative governance. Professor Shiau received his Master's and Ph.D. degrees in Industrial Engineering from Arizona State University, USA. His primary research interests encompass the applications of information systems, cross-border e-commerce, operations management, and business models. His scholarly works have been published in a wide range of reputable international journals, including *Computers in Industry*, *Computers & Industrial Engineering*, *International Journal of Production Research*, *International Journal of Production Economics*, *International Journal of Manufacturing Technology and Management*, *International Journal of Systems Science: Operations & Logistics*, *Journal of Information and Optimization Sciences*, *Internet Research*, *International Journal of Logistics Systems and Management*, and *International Journal of Industrial Engineering*, among others. Moreover, Professor Shiau has actively presented his research findings at numerous prestigious international conferences, such as the IEOM, ICNSC, IEEE SOLI, CIE, and the IISE Annual Conference and Expo, as well as other major international academic forums.