

SELECTION PROCESS FOR AN AUTOMATED STORAGE SYSTEM: A UNISON FRAMEWORK APPROACH

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ABSTRACT

An automated storage system (ASS) is a computer-controlled warehousing system that is used to manage and automatically pick and place parts/goods. A good automated storage system can maximise space and shorten shipments' response time, thereby helping the company to adapt quickly to an ever-changing market. For many enterprises there is also an urgent need to establish and install ASS. However, many companies find it difficult to design and install the right ASS. Many considerations need to be examined in choosing a suitable ASS, given their various capacities and capabilities. This study aimed to employ the UNISON framework to present a comprehensive model for selecting the most suitable ASS. It identified two fundamental objectives in the ASS selection process: (1) choosing the most suitable design for ASS; (2) choosing the most competent vendor to build and implement the ASS. This study then broke the fundamental objectives down into more detailed mean objectives and attributes. After defining the mean objectives and attributes, the study created a key performance indicator to assess the selection process. An empirical study was conducted among small and medium-sized enterprises (SME) in Taiwan to validate the proposed framework. A qualitative study was then developed by interviewing three related stakeholders – the vice president, the head of the production department, and the senior engineer – to support the identification process in selecting and implementing the ASS. From this case study, we found that our ASS selection model showed good practical viability.

OPSOMMING

'n Outomatiese bergingstelsel (ASS) is 'n rekenaarbeheerde pakhuisstelsel wat gebruik word om onderdele/goedere te bestuur en outomaties te kies en te plaas. 'n Goeie outomatiese bergingstelsel kan ruimte maksimeer en verskepings se reaksietyd verkort, en sodoende die maatskappy help om vinnig aan te pas by 'n steeds veranderende mark. Vir baie ondernemings is daar ook 'n dringende behoefte om ASS te vestig en te installeer. Baie maatskappe vind dit egter moeilik om die regte ASS te ontwerp en te installeer. Baie oorwegings moet ondersoek word by die keuse van 'n geskikte ASS, gegewe hul verskillende deursette en vermoëns. Hierdie studie het ten doel gehad om die UNISON-raamwerk te gebruik om 'n omvattende model aan te bied vir die keuse van die mees geskikte ASS. Dit het twee fundamentele doelwitte in die ASS-seleksieproses geïdentifiseer: (1) die keuse van die mees geskikte ontwerp vir ASS; (2) die keuse van die mees bekwame verkoper om die ASS te bou en te implementeer. Hierdie studie het dan die fundamentele doelwitte opgebreek in meer gedetailleerde gemiddelde doelwitte en eienskappe. Nadat die gemiddelde doelwitte en eienskappe gedefinieer is, het die studie 'n sleutelprestasie-aanwyser geskep om die keuringsproses te assesseer. 'n Empiriese studie is onder klein en mediumgrootte ondernemings (KMO) in Taiwan gedoen om die voorgestelde raamwerk te bekratig. 'n Kwalitatiewe studie is toe ontwikkel deur onderhoude te voer met drie verwante belanghebbendes -

die visepresident, die hoof van die produksiedepartement en die senior ingenieur - om die identifikasieproses te ondersteun in die keuse en implementering van die ASS. Uit hierdie gevallestudie het ons gevind dat ons ASS-seleksiemodel goeie praktiese lewensvatbaarheid getoon het.

1 INTRODUCTION

Industry 4.0 has led to the creation of intelligent warehouse systems. One of the critical directions in their development is the implementation of automated storage systems (ASSs), mainly in automated factories, distribution centres, warehouses, and non-manufacturing environments. In distribution centres, various products are received, stored, and distributed to customers with ASS. The manufacturing process, in contrast, has different operations, keeping the raw materials for production purposes and the products for further distribution [1]. The market size of ASSs is growing, and is projected to reach US\$ 12,928 million by 2027 [2].

The adoption of ASS is increasing in line with the need for them in all industrial sectors. Although there is a significant adoption rate of ASSs in warehouse systems, companies face a tough decision when choosing the correct and most suitable ASS. The literature has mainly discussed and emphasised the technical part of the ASS selection process, while only limited studies have captured the critical points in selecting ASS from a company's strategic perspectives [3] [4] [5] [6].

This study aims to fill the existing gap by structuring a company's strategic objectives to help it to adopt the correct and most suitable ASS. In this study, the UNISON framework [7] [8] is implemented to study the selection process for ASS.

This study makes both practical and theoretical contributions. First, it contributes by using the decision analysis UNISON framework in a new case study. By employing the UNISON framework in this case, it offers a different view of the framework's use. Second, this study helps to frame and structure a company's objectives to determine, design, and build ASS in warehouse operations. It requires an understanding of the stakeholder's overall requirements and needs from the shareholder, owner, and employee points of view.

This study is organised as follows. Section 2 reviews some fundamental literature in this field. Section 3 introduces the proposed research framework for choosing the correct ASS. Section 4 details the empirical research into ASS selection in plastic manufacture in Taiwan for validation. Section 5 concludes this study by summarising it, addressing its limitations, and proposing future studies.

2 LITERATURE REVIEW

2.1 Automated storage system

Storage and retrieval systems have played an essential role in logistic operations since their first development in the 1950s, when the focus was on the fundamental concept of storage, including dimension storage and the number of racks [9]. Roodbergen and Vis [10] developed a literature study on the system design and control problem for a static environment. Essentially, ASS integrates control and the equipment used to handle, store, and retrieve material in response to its production and the customer. That integration made the ASS relatively reliable, with its speed, precision, and accuracy driven by high automation systems.

In Industrial Revolution 4.0, with advanced technology, the Internet of Things (IoT), artificial intelligence (AI), and integration between humans and machines, ASSs were developed to be deeply involved in many areas, particularly storage and warehousing. Some aspects were developed to address issues related to the dynamic environment and the relationship between ASS and material handling systems in production and distribution facilities. Nativ, Cataldo, Scattolini, and Schutter [11] developed the predictive model control of ASS based on mixed logical dynamic (MLD) modelling to control ASS. Technology integration supports an automated guided vehicle (AGV) using the system-engineering approach [12]. Smart factory system requirements are developed on the basis of survey and perspective [13]. An advanced study by Kazemi [14] offered a hybrid solution procedure that integrated adaptive extensive neighbourhood search and ant colony formulation to solve problem complexity in a large-scale inventory.

Many manufacturing, logistics, distribution, and retail companies optimise the use of ASS because it has many advantages – for instance: (1) reducing human involvement in storage and retrieval processing material; (2) lowering labour costs; (3) maximising the use of space; (4) increasing productivity; (5) speeding up the pick-up process and increasing its accuracy and precision of goods storage/retrieval; and (6) real-time monitoring and inventory control. Therefore, with many benefits and increasingly advanced technological developments, the growth of ASS is entering a golden age. ASS technology can be developed in five categories: ASS device load, ASS mini-load, ASS person-on-board, ASS deep-track, and automatic object retrieval systems [15].

Although it has many benefits, the use of ASS requires a significant investment in machines and equipment, installation, computer systems, and professional development. Of the total initial investment in mini-load ASS alone, ASS machines represent 40% or more of a warehouse's cost [16]. For this reason, the selection of the right ASS system needs to be carefully considered to avoid investment mistakes. In designing the ASS system, it is necessary to consider an industrial scale's suitability and many other aspects related to tangible dimensions.

2.2 Analytical hierarchy process

In the late 1970s, Saaty developed AHP as a systematic way to define priorities and support complex decision-making. The analytical hierarchy process (AHP) is a method that uses pairwise comparisons and the judgement of experts to derive priority scales in the decision-making process. AHP provides a holistic framework for solving problems, based on multi-criteria and multi-actor decision-makers [17] [18]. Generally, AHP is one multi-criteria decision-making method that is user-friendly and flexible [18]. The main benefits of AHP are that it enables problem-solving with hierarchical modelling, decision-making, and maintaining consistency. There are three main functions in AHP structures: structuring complexity, measurement, and synthesis.

AHP is a popular tool in decision-making, and is widely used in many industries. From 2013 to 2017, 2,600 scholarly publications in reputable journals used AHP in studies related to the decision-making process [19]. For the past ten years, AHP has been used in a specific mathematical model sector, supply chain management and logistics, computer science, engineering, environmental science and technology, and business management, integrating other methodologies such as DEA (Data Envelopment Analysis), QFD (Quality Function Deployment), SWOT analysis, and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). AHP has also been used in human resources development cases such as measurement skills and organisational performance [20] [21]. Table 1 shows the recent application of AHP in supply chains.

Table 1: Recent implementation of AHP

Author (year)	Context	Methodology
Korpela <i>et al.</i> (2007) [22]	Warehouse selection operator	AHP and DEA
Awasthi & Chauhan (2012) [23]	Sustainability city logistics planning	Affinity diagram, fuzzy AHP, and fuzzy TOPSIS
Lia and Kao (2014) [24]	Logistics systems	Fuzzy AHP, QFD, and multi-segment programming
Park <i>et al.</i> (2019) [25]	Location selection warehouse stores	AHP
Aktan & Tosun (2013) [26]	Selection ASS	AHP and TOPSIS
Vieira <i>et al.</i> (2017) [27]	Warehouse location and distribution centres	AHP
Kahraman <i>et al.</i> (2020) [15]	Selecting a suitable ASS	Interval-valued intuitionistic fuzzy AHP

2.3 UNISON research framework

To understand clearly the ASS selection process, we proposed a research methodology that employed the UNISON decision analysis framework, which proposes integrated systematic stages for a comprehensive decision process analysis [28] [7]. It has six main steps: (1) understanding and defining problems; (2) defining the niche for decision quality improvement; (3) structuring the objective and the influencing relationship; (4) identifying and describing the expected outcomes; (5) making overall judgements and value assessments; and (6) making tradeoffs and decisions. These are shown in Figure 1. The UNISON framework has been developed effectively by scholars in many areas of decision-making problems, including selecting alternative IC strategies [7], knowledge management of UIC collaboration [28], and innovative products for design by extracting user experience [29].

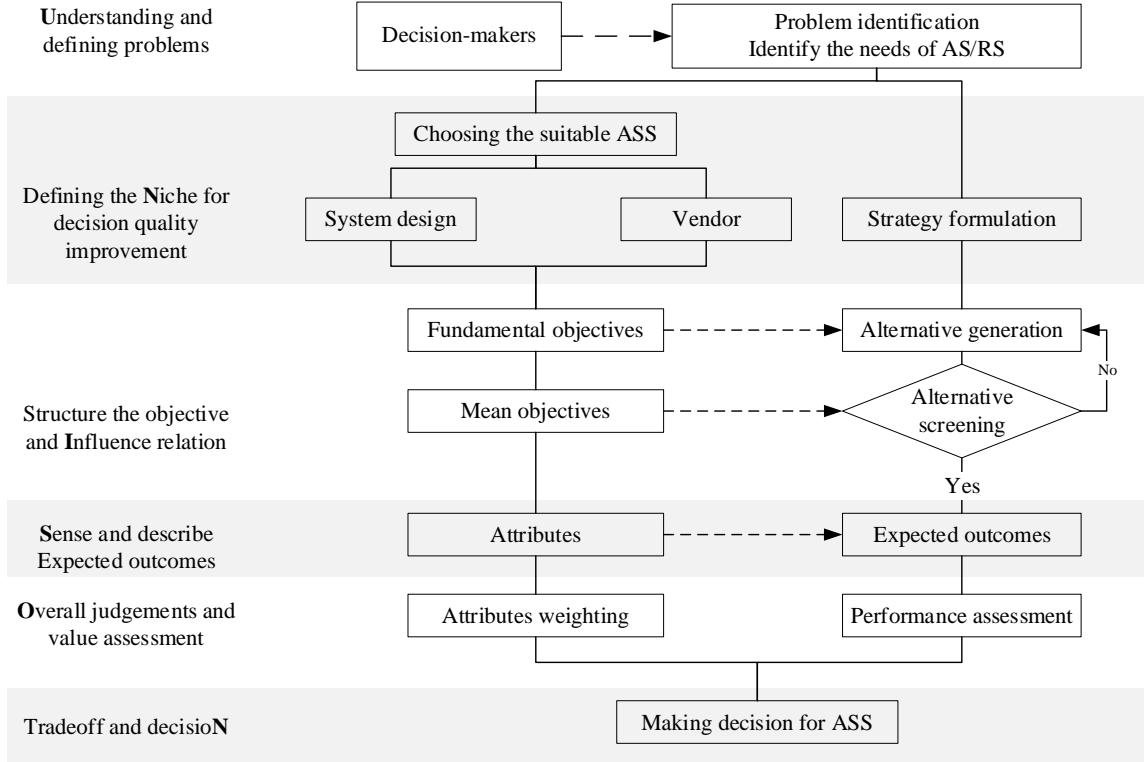


Figure 1: UNISON research framework for automated storage system selection

3 RESEARCH FRAMEWORK AND METHODOLOGY

3.1 Understanding and defining the problem

Structuring the problem was the first step to ensuring that the ASS selection ran smoothly with the subsequent activities. In this stage, a decision-maker should understand the main reason for ASS implementation and investigate the issue. Besides, decision-makers undertake a deeper analysis to understand the internal capacity and capability, collecting a wide range of information about ASS usage, its benefits, challenges, and cost, and the current and future development of ASS technology. The data can be gathered from different sources, including domain experts, academic journals, magazines, exhibitions, news outlets, and other relevant documents.

3.2 Defining the niche for decision quality improvement

The next step of the research framework was to facilitate improved decision quality. The ASS selection problem should accommodate inputs from stakeholders, project objectives, and project risks. The stakeholders as decision-makers are the most important to the company: they need to have qualifications related to their jobs and comprehensive knowledge of the business process of the company. This study highlights two main categories for ASS selection: (1) choosing the right vendor; and (2) building and implementing the most suitable ASS design. The vendor selection process involves seeing whether the client and the vendor have the same goals, and ensuring the project's completion on time. The question of the most suitable vendor is based on many criteria, which can be found in section 4.3 and Figure 3.

3.3 Structure the objective and influence relation

Structuring the objectives helped the project leader and the teams to frame goals and then incorporate these objectively and appropriately into their decision model. Strategic objectives lay a solid foundation for decision-making, and can be used as a reference point for poorly structured decision situations [30] [31]. We developed the fundamental objectives and means objectives to help the project teams to identify the company's capacity and capability, its business attributes, its project goals, and the industry's environment. The project goal was one of the criteria in the process of selecting ASS. Means objectives

were described and elaborated on the basis of the fundamental objectives. We employed fundamental objectives to generate the vendor and design alternatives.

Vendor-specific information was collected from different sources, such as company websites, news outlets, and other reliable information sources. Furthermore, we used the mean objectives to eliminate the vendors and designs that did not meet our needs. We could rescreen the alternatives using the two objectives if we did not get suitable alternatives.

3.4 Sense and describe expected outcome

The attributes, characterised as complete, measurable, decomposable, non-redundant, and minimal [32] [33], were generated from the fundamental and mean objectives. The attribute generation had an effect on the evaluation of the existing alternatives. The project team evaluated the attributes iteratively, and modified the set of attributes.

This research generated attributes, both qualitative and quantitative, to help the company to assess the suitable and proper choice of ASS. The mean objectives helped the project team to frame the critical objectives that the project needed to achieve. Discovering the measurable attributes indicated the degree to which the corresponding objective was achieved, based on the stakeholder's requirements, internal capacity, and capability, and on the manufacturing operations in a specific industry.

3.5 Overall judgement and value assessment

Team members analysed the qualified ASS vendor and the design that matched the requirements. Aggregating weights could yield the relative importance of the attributes and the decision-maker's priority over the hierarchy. In this stage, the decision-maker made a pairwise comparison using AHP. The project team discussed and evaluated those criteria, and consolidated them into a single decision to represent the company's decision. In this study, we discuss the three main stakeholders involved in this project. The project team was selected on the basis of their position (having privilege in decision-making), their expertise related to their job (particularly in relation to ASS), and their holistic knowledge of the business process of the company.

3.6 Trade-off and decision

The ASS selection framework's final stage was to select the most suitable vendor and design, based on the AHP pairwise comparison. After choosing the vendor and the system design, the team members could continually evaluate and monitor the progress of the vendor's performance during the project's implementation. This continual performance evaluation would help the company to check the vendor's competence in designing and building ASS.

4 EMPIRICAL STUDY: CASE STUDY OF AN SME IN TAIWAN

4.1 Understanding and defining the problem

Following the proposed UNISON framework, an empirical study was conducted in an SME in Hsinchu, Taiwan. This plastic manufacturing company wanted to build an ASS for its series of household products. The objectives of the project were (1) to use the warehouse space, (2) to pick and place parts/goods in the warehouse quickly, and (3) to shorten the response time for shipments. Taking into account many requirements, such as cost-effectiveness, use of space, fast response times, correct access to goods, minimal use of manpower, and connecting easily to the information system, this UNISON framework was a holistic approach that was easy to develop systematically and whose steps were easy to follow. The UNISON framework was adopted to help top management make decisions in choosing the most suitable ASS system to match their capacities and capabilities.

4.2 Defining the niche for decision quality improvement

A project team was formed to implement the ASS project that included stakeholders such as the vice president, the head of the production department, the senior engineer, the purchasing manager, and members of staff. The stakeholders were the most important to the company as decision-makers, as they had expertise related to their jobs, knowledge of the business process and ASS, and the decisions that would directly affect their jobs. First, it was crucial for team members to understand the goal, scope, strengths, and weaknesses of the project. The project team found two main factors in choosing a suitable ASS: the vendor and the system design. These two main factors were firmly based on the project's scope and/or weaknesses.

4.3 Structure the objective and influence relation

The process of constructing the objective structure is based on the analytical approach, the top-down decomposition method, and the domain knowledge from decision-makers. The strategic objective of the study was to select a suitable ASS. Several meetings were held with the project team members to construct the fundamental objective and the mean objectives. The fundamental objectives were extracted from the qualitative data of the stakeholders and their expectations related to the strategic objectives of the study, which were focused on the high-level strategic objectives of the ASS vendor and the ASS design. The high-level strategy was decomposed into lower-level feasible objectives. In this case, the level of the feasible objectives of an ASS vendor consisted of the ASS's characteristics, CRM (Customer Relationship Management), and technical capability. Meanwhile, the ASS design had to meet a number of feasible objectives: maximising the use of space, matching the design to the characteristics of the product, minimising the design's cost, its functionality, its user-friendliness, and ease of maintenance (see Figure 2).

The purchasing department searched for vendors, using the fundamental objectives. Initially twelve vendors were selected for the screening process. The low-level feasible objectives were decomposed to extract the hidden knowledge and the important mean objectives in relation to the details of the vendors and the ASS design, as shown in Figures 3, 4a, and 4b. Given the requirements derived from the means objectives for the vendor factors, such as financial performance, number of employees, past successful projects, after-sales service, product category, number of patents, upgrading the technology, and the technical criteria (Figure 3), the screening process was implemented to choose the final three vendors for consideration. Meanwhile, the means objective for the ASS design consisted of the dimensions and capacity of the storage, the products' properties and treatment, the detailed costs, picking and placing products, the time needed to move them, the system's connectivity and integration, real time inventory, safety, easy-to-use interface, ease of learning and operation, and details of maintenance (Figures 4a and 4b). The shortlist of vendors was discussed with the project team to make the final decision. If the shortlist did not satisfy the project team, the process of generating alternatives would start again to find new vendors. Finally, each vendor proposed an ASS design and explained the project in detail for the company to consider and make a decision.

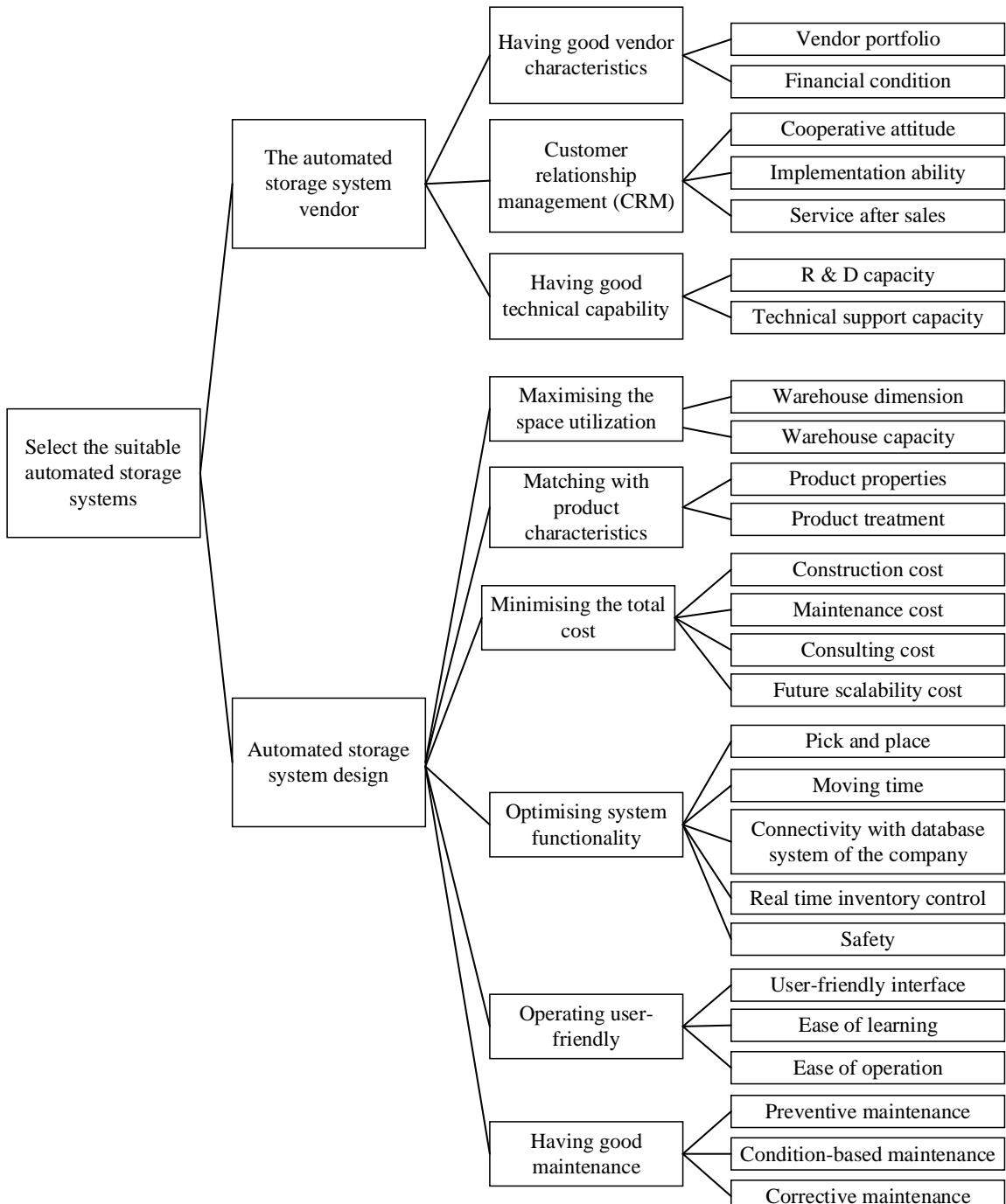


Figure 2: Fundamental objectives

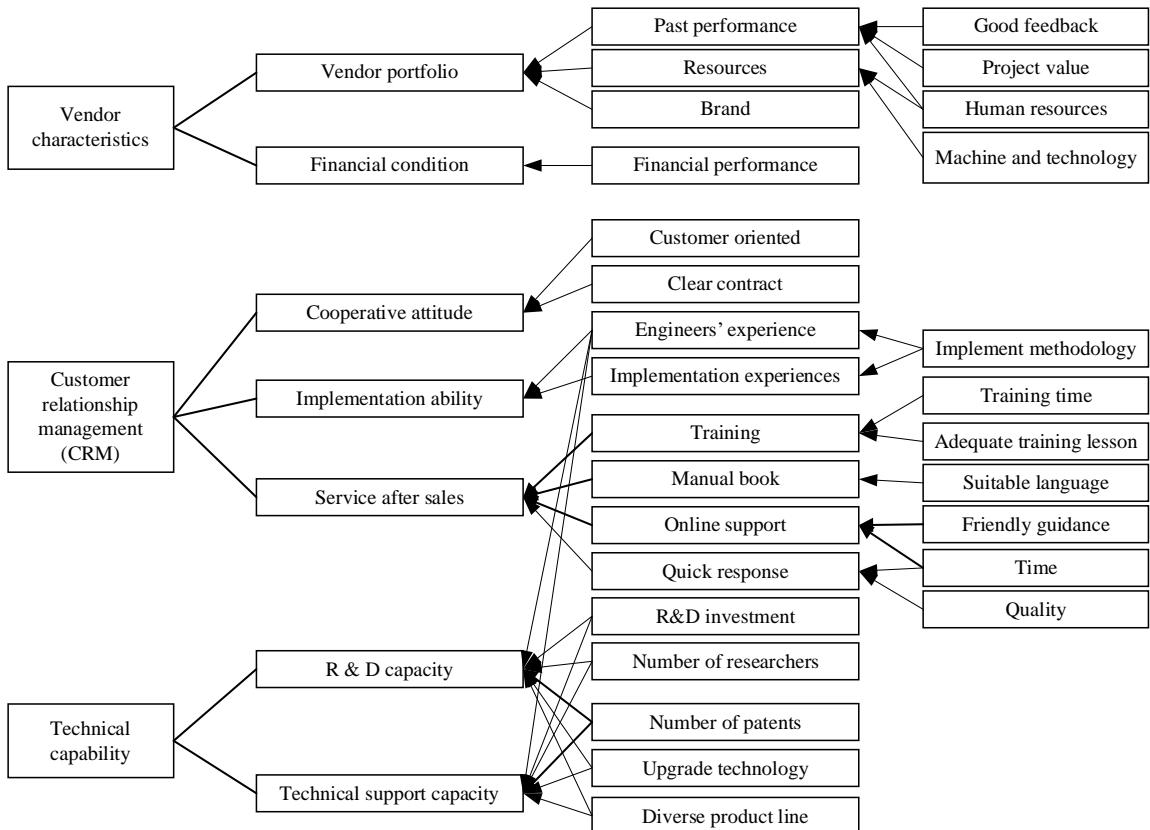


Figure 3: Mean objectives (vendor factors)

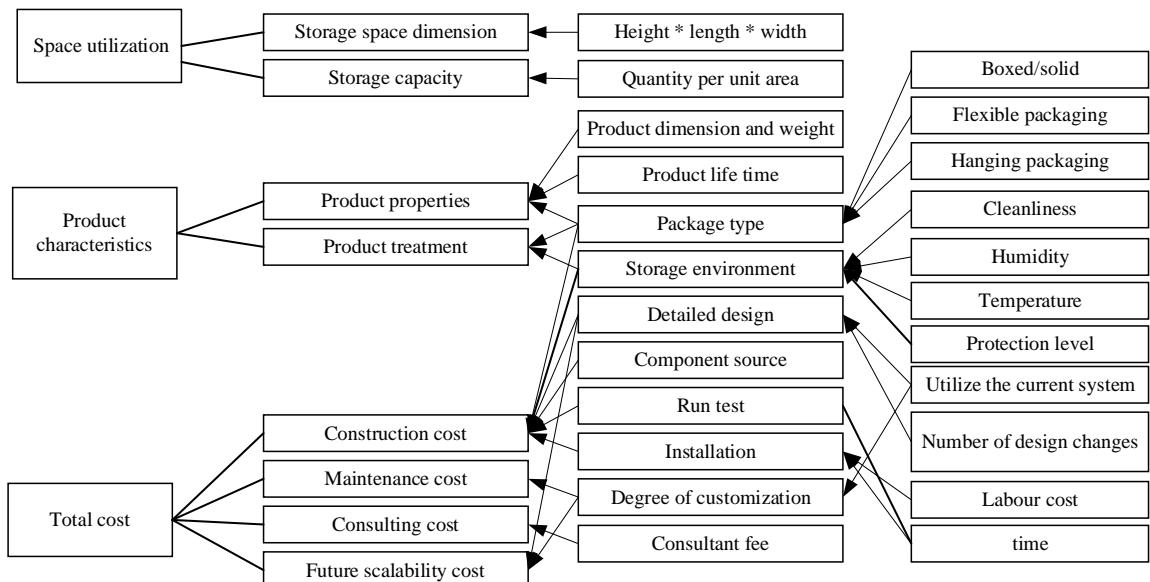


Figure 4a: Mean objectives (system design factor)

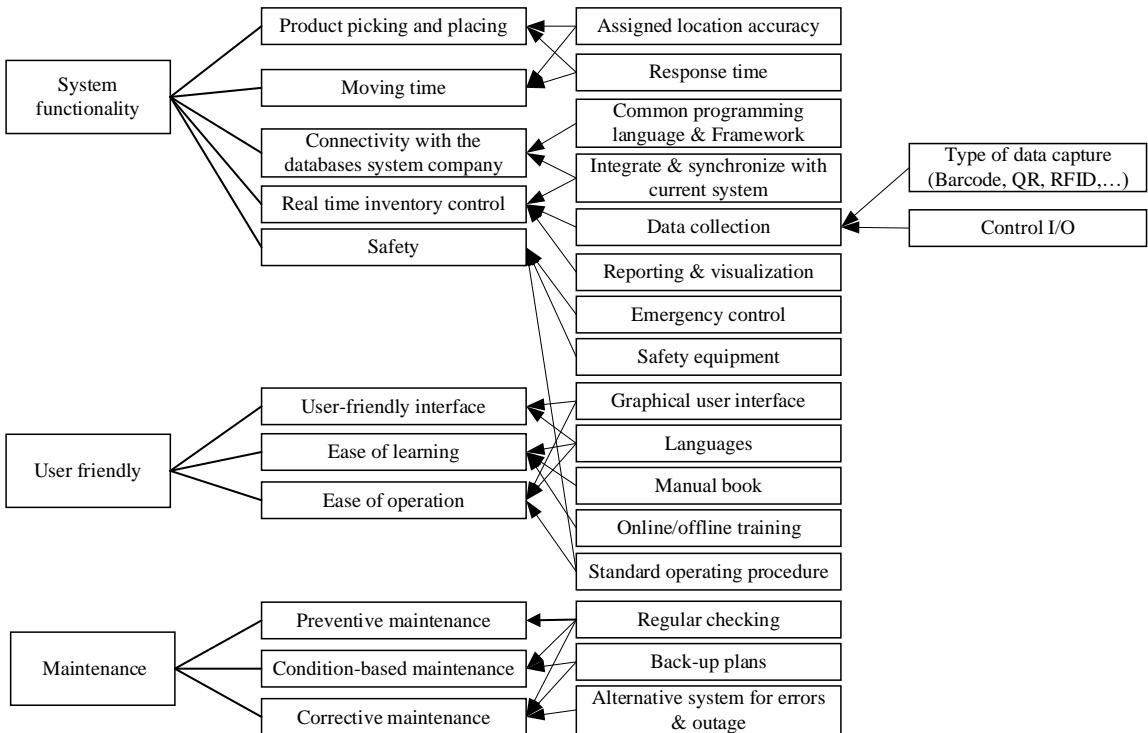


Figure 4b: Means objective (system design factors)

4.4 Sense and describe expected outcome

The AHP hierarchy was derived from the fundamental objective hierarchy with the four levels shown in Figure 5. Level one contained the strategic objective of choosing the most suitable ASS. Level two consisted of two lower levels as the two main objectives. Level three identified the attribute criteria to measure and evaluate the ASS systems' designs and the vendors respectively. Finally, level four included the alternatives among the ASS systems after the screening process described in subsection 4.3 above. Referencing the mean objective hierarchy, the evaluation criteria and measurements, as shown in Table 2, were established to assess the attributes.

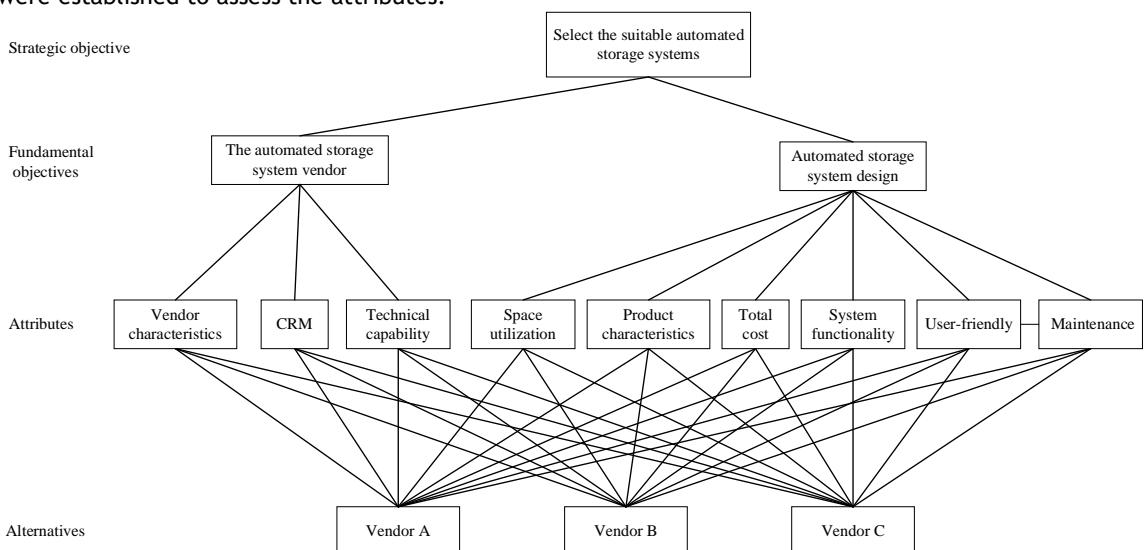


Figure 5: Attributes and AHP hierarchy

Table 2: The evaluation criteria and measurements for attributes

Fundamental objective	Attributes	Evaluation items	Measurements
A. The automated storage system vendor	A1. Vendor characteristics	1. Vendor portfolio	1. Number of successfully implemented projects
			2. Scale of the project has been done. Scale of the project is related to projects that have been completed in the past.
			3. Brand
		4. Finished product diversity	
	A2. CRM	2. Financial condition	1. Financial stability. The company has a record of good performance in making profits, according to its financial report.
		1. Cooperative attitude	1. Good communication
			2. Good problem-solving. The indicator is based on the assessment that is conducted by stakeholders qualitatively.
		2. Ability to implement	1. The number of employees involved in a project
			2. Good qualifications in the project team
			3. Good project management
	A3. Technical capacity	3. After-sales service	4. Feasible project's implementation time
			1. Online support/service
			1. Engineers' level of experience
			2. Number of inventions
		1. R&D capacity	3. Number of researchers
			4. Domain knowledge
B. Automated storage system design	B1. Space utilisation	2. Technical Support Capacity	1. Upgrade technology service
		1. Storage space dimensions	1. Current space utilisation
		2. Storage capacity	2. Quantity per unit area
	B2. Product characteristics	1. Product properties	1. Product and storage matching
		2. Product treatment	1. Good adaptable treatment of product
			2. Good adaptable environment
		1. Construction cost	
	B3. Total cost	2. Maintenance cost	1. Limited project budget from the company
		3. Consulting cost	2. Limited annual maintenance budget
		4. Future scalability cost	3. Availability of infrastructure
	B4. System Functionality	1. Pick and place	1. Assigned location accuracy
		2. Moving time	1. Quick response time

Fundamental objective	Attributes	Evaluation items	Measurements
		3. Connectivity with database system of the company	1. Good interoperability
		4. Real-time inventory control	1. Accurate & timely reports 2. Reliable Reports
		5. Safety	1. Good safety plan
	B5. User-friendly	1. User-friendly interface	1. Multi-language 2. Good user privilege management
		2. Ease of Learning	1. Good operating manual 2. Good training (online/offline)
		3. Ease of operation	1. Online help 2. Simple graphical user interface
	B6. Maintenance	1. Preventive maintenance	1. Good regular checking
		2. Condition-based maintenance	1. Good backup plans
		3. Corrective maintenance	1. Good alternative system for errors & outages

4.5 Overall judgement and value assessments

Following the AHP methodology, the pairwise comparison with nine scales based on each attribute and the comparison between attributes was developed to determine the normalised weight. The pairwise comparison matrix between the attributes was discussed and evaluated by all of the decision-makers, as shown in Table 3a for vendor selection and in Table 3b for system design. The priority weights of the attributes from all of the decision-makers were evaluated, and are shown in Table 4. Table 5 shows the evaluated results of the relative weight for each alternative. Vendor and system design C were the best options for the company. The consistency ratio (CR), which should be less than 0.1, was used to check the consistency of the decision-makers' pairwise comparison [15].

Table 3a: Attribute pairwise comparison evaluation by decision-maker 1 for vendor selection

Attribute pairwise comparison	Vendor characteristics	CRM	Technical capability
Vendor characteristics	1	1/3	1/7
CRM	3	1	1/2
Technical capability	7	2	1

Table 3b: Attribute pairwise comparison evaluation by decision-maker 1 for system design

Attribute pairwise comparison	Space utilisation	Product characteristics	Total cost	System functionality	User-friendly	Maintenance
Space utilisation	1	4	1	4	7	3
Product characteristics	1/4	1	1/3	1/2	6	1/3
Total cost	1	3	1	3	8	4
System functionality	1/4	2	1/3	1	5	2
User-friendly	1/7	1/6	1/8	1/5	1	1/3

Attribute pairwise comparison	Space utilisation	Product characteristics	Total cost	System functionality	User-friendly	Maintenance
Maintenance	1/3	3	1/4	1/2	3	1

Table 4: The priority weights of attributes from decision-makers

Factor	Attributes	All decision-makers
Vendor	Vendor characteristics	0.093
	CRM	0.292
	Technical capability	0.615
System design	Space utilisation	0.320
	Product characteristics	0.093
	Total cost	0.310
	System functionality	0.135
	User-friendly	0.031
	Maintenance	0.112

4.6 Trade-offs and decision

As shown in Table 5, the relative weight results for each alternative from the evaluation were established. All pairwise comparisons were investigated to ensure that the evaluation process was fully consistent. Based on the comprehensive UNISON framework, the overview of the whole method for ASS selection was provided to top management for the final decision in choosing the vendor and a suitable ASS. The ASS was designed and implemented by vendor C – the one found to be most suitable. The three vendors had both weaknesses and strengths in their products, and the company needed to choose the one that best fitted its requirements. Besides, they were so competitive with each other that the differences between the scores were relatively small.

Table 5: Results of AHP analysis

Alternatives	All decision-makers
Vendor A	0.157
Vendor B	0.313
Vendor C	0.530

5 CONCLUSION

This study successfully used the UNISON framework to construct a holistic approach to choosing the most appropriate ASS. This research has shown our ability to systematise some processes in selecting ASS. We could structure the objectives, starting from the fundamental objectives, the means objectives, and the attributes. An empirical study validated the proposed framework at a plastic manufacturer in Hsinchu, Taiwan. By conducting this empirical research, we proved that our proposed framework could under practical conditions.

We address two limitations in our research. First, we conducted a study in a single company. As we could see, other companies might emphasise different criteria. Thus any future study would need to use our framework in other industries, such as chemical, food and beverage, or pharmaceutical companies. These industries can be categorised as dealing in perishable products. Employing the framework in different industries would lead to the greater generalisability of our models. Second, we used only one pairwise comparison in evaluating the attributes and the alternatives. Future studies could be designed to implement other multi-criteria decision-making methods.

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