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Constructing a Core Competency Model for Entry-Level Engineers and Technicians in the LED Lighting Industry: An Analysis Based on DACUM-AMOD and Fuzzy Delphi Method

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ABSTRACT: This study aims to analyze the core competencies required for entry-level engineers and technicians in the LED lighting industry, specifically in the areas of epitaxial, crystal grain, package, and lighting products. It focuses on departments such as research and development, manufacturing, and analysis. The analysis employs a modified DACUM-AMOD method and the Fuzzy Delphi Technique. The process involved 25 industry experts from listed companies in the domestic LED lighting sector and included four stages: expert meetings, DACUM-AMOD sessions, expert reviews, and fuzzy Delphi surveys. Through this process, the required competencies were identified, including 25 responsibilities, 77 tasks, and 299 competencies. Each task was classified according to the necessary education level, and each competency was rated based on entry-level strength. The findings provide a reference for talent selection, training, assessment, utilization, and future research.

Keywords: *LED lighting industry; engineering and technology education; fuzzy Delphi technique; DACUM-AMOD; competency analysis.*

1 INTRODUCTION

With the advent of the low-carbon economy, the development of energy technologies is not only crucial for the shared well-being of humanity but also directly impacts the economic development of nations and regions. The LED lighting industry, as a key product for energy conservation and carbon reduction, plays a significant role in cultivating domestic energy technology talent, creating employment opportunities, and promoting the industry's shift towards low-carbon, high-value development. At the same time, it has become one of the most important industries in the development of national green energy sectors.

In the face of global economic competition, technological advancements, and industrial changes, there is an urgent need for an objective system to analyze the professional competencies required by entry-level engineers and technicians in this industry. This can be achieved through scientific methods to establish a work content directory (also referred to as a competence profile) for these roles. Such an analysis would guide or review the curricula of relevant departments and academic programs, ensuring they align with industry needs and help reduce the gap between supply and demand.

Although many universities in China have already established LED lighting-related departments or programs and offer relevant courses to cultivate demand-driven, high-quality talent, the professional competencies required for entry-level engineers in the LED industry have yet to be properly defined through appropriate research methods. According to the Ministry of Education of China, the number of graduates from university engineering and technology-related programs should theoretically meet the needs of domestic high-tech and manufacturing industries. However, a comparison of these graduates with those entering the high-end LED technology sector reveals a mismatch. This discrepancy highlights the impact of rapid technological changes on industries, economies, and the environment, showing that the undergraduate talent cultivated by universities is struggling to keep up with the fast-paced development of businesses and the trends of global division of labor. This misalignment with the required competencies leads to a talent shortage in the LED lighting industry.

According to Zhaopin data, in 2024, there will be 11.79 million university graduates in China, of whom only 48% have received job offers, meaning they have successfully signed contracts with companies (NetEase, 2024). These results indicate that companies are facing a "labor shortage" dilemma, suggesting that talent training institutions (or universities) have not adequately considered national development and industry needs. This mismatch between the supply and demand of talent in academia and industry, where professional qualifications do not align, underscores the need for a comprehensive review of technological talent cultivation and the supply-demand gap, as well as a thorough reassessment of education and industry policies.

Therefore, it is essential to analyze the job tasks and competencies required for entry-level engineers and technicians in the LED lighting industry using scientific methods, in order to guide or review the curricula of relevant departments/programs to align with industry needs. Only by thoroughly understanding the industry's requirements can a curriculum be developed that meets the sector's needs and responds to environmental changes and challenges. This approach will educate talent capable not only of adapting to today's technological society but also of facing the technological society of the future. Hence, developing a suitable framework for training talent in green energy technologies at existing universities and colleges will serve as a reference for talent selection, utilization, development, and retention in related industries.

This study focuses on the front-end of the LED lighting industry's smiling curve, which includes departments such as R&D, innovation, design, and manufacturing. By involving experienced practitioners in advanced LED lighting, this research employs the modified DACUM-AMOD method and the fuzzy Delphi technique to develop a list of responsibilities, tasks, competencies, and required education levels for entry-level engineers and technicians. This will serve as an important interface between the labor market and the education and training systems (European Training Foundation [ETF], 1999), providing universities with the information needed to develop curricula that are more closely aligned with actual job requirements. By narrowing the gap between talent cultivation and employment needs, this will help foster new opportunities in the LED lighting industry.

Specifically, the objectives of this study are as follows:

- To propose a competency profile for entry-level engineers and technicians in the LED lighting industry, including responsibilities, tasks, and required competencies.
- To identify the required educational level and competency levels for entry-level engineers and technicians in the LED lighting industry.

2 LITERATURE REVIEW

2.1 Competency and Core Competency

Competency (also referred to as "competence") refers to the knowledge, attitudes, and skills necessary to perform tasks or engage in work activities. It represents an individual's demonstrated behaviors and encompasses both explicit skills and knowledge as well as implicit characteristics related to specific performance outcomes (Weinert, 2001). This concept began emerging in the early 1950s and has since become a key term in occupational analysis, focusing on identifying and defining the behaviors—such as attitudes, cognition, and personal traits—that contribute to exceptional performance. The aim is to help organizations, institutions, or individuals enhance their work performance (Chen & Chen, 2005; McClelland, 1973). In response to the rapid global changes and the increasing demand for skilled human resources, developed countries such as the United States, the United Kingdom, Australia, and New Zealand have established competencies across a broad range of occupations. These competencies aim to cultivate high-quality human resources and strengthen international competitiveness (Hamel, 1994; Prahalad & Hamel, 2012).

Competency can be measured through behavioral indicators that reflect the knowledge, skills, self-image, social motivation, thinking, attitudes, feelings, and other traits gained through learning or experience. These competencies apply to basic abilities across various aspects of personal life. Scholars, both domestically and internationally, have provided numerous interpretations of the term "competency" (or "competence"). For example, competency can be defined as the fundamental characteristics of individuals that lead to effective or exceptional work performance, which includes motivation, skills, self-concept, social roles, and verifiable knowledge (Boyatzis, 1982; Ledford, 1995). These traits—comprising an individual's knowledge, skills, and behaviors—are the combination of both explicit and implicit characteristics. They are not only related to a person's job responsibilities but can also predict or influence their behavior and performance (Draganidis & Mentzas, 2006).

Spencer and Spencer (1993) introduced the "Iceberg Model" to describe the various dimensions, components, and characteristics of professional competencies. They proposed that competencies can be categorized into five basic characteristics: motives, traits, self-concept, knowledge, and skills. Of these, knowledge and skills are more explicit and easier to develop into personal abilities. They can be improved through training and learning to achieve higher performance (Vargas Zuñiga, 2004). Regarding cultivation, acquiring these explicit competencies through training and development methods is more cost-effective. In contrast, implicit motivations, traits, and self-concept are deeper, less detectable characteristics that, while they can be developed through education, are harder to measure in terms of their benefits (Spencer & Spencer, 1993).

Nordhaug (1993) categorizes competencies into three dimensions: industry-specific, firm-specific, and task-specific. These are further distinguished as meta-competence, standard technical competence, industry competence, technical trade competence, intra-organizational competence, and unique competence, as shown in Figure 1. In essence, competence refers to the behavioral traits of individuals who perform at a high level in their work. High performance in the workplace must be identifiable and measurable objectively. Therefore, performance standards serve as a reference, and there is a causal relationship between competence and individual performance. Competence encompasses multiple dimensions of traits and behaviors and can partially describe high-performance behaviors (Chen, Wang, & Zhou, 2023).

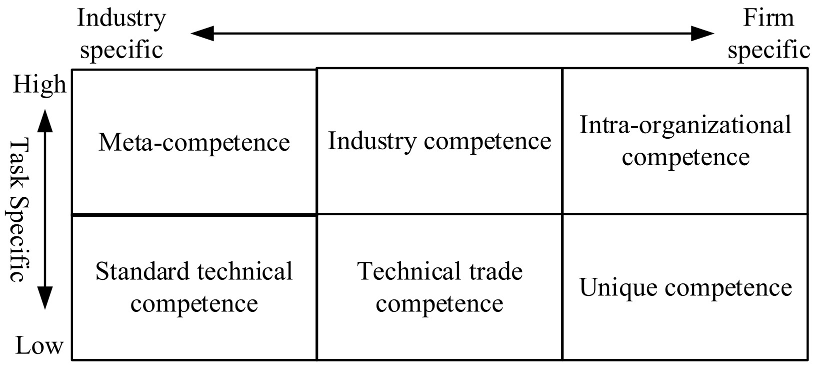

Figure 1. Types of competency

Due to the varying perspectives of scholars on the interpretation of competencies, there is currently no unified definition of competency. For example, scholars such as Boyatzis (1982), Employment and Training Administration (ETA) (2010), Horng, Hsu, Liu, Lin and Tsai (2010), McClelland (1973), Tian (2006), Woodruffe (1991), and Vargas Zuñiga (2004) have approached the concept from different angles—some focus on the work itself, others on the individual, some explore the competency requirements for human resources "specialized talents," some define competency in general terms, while others emphasize behavioral analysis, i.e., the analysis of individual abilities. Additionally, competency is often categorized into "core competencies" and "professional competencies." These competencies include the knowledge, attitudes, and skills required to complete specific tasks or jobs within a given profession.

Competencies can be understood as reflecting the result-oriented performance exhibited by individuals in work activities. They emphasize the ability to act within a work system and reflect the following characteristics: based on knowledge, demonstrated through skills, ensuring quality through attitudes, and other traits (such as affective factors) that act as key determinants of success or failure. In addition to knowledge and skills, competencies should also encompass implicit, latent aspects. That is, competency should include both essential core elements and actual specialized performance (ETA, 2012), which serve as behavioral standards that enable individuals to perform their jobs effectively. Beyond the knowledge, skills, and attitudes required for the job, competencies can also be used to understand or predict an individual's work performance. In addition to the explicit knowledge and skills already possessed, there is a need for education to develop the latent, implicit aspects. Since competencies include both explicit and implicit dimensions, explicit competencies like knowledge and skills are easier to develop into personal abilities and can be enhanced through education, training, and learning to achieve higher effectiveness. In contrast, the implicit dimensions of competencies are deeper and more difficult to express; although they can be developed through training and education, their benefits are less easily quantified (Lim, Chan, & Dallimore, 2010; Spencer & Spencer, 1993). Therefore, this study primarily focuses on the specific competencies that are required for entry-level engineers and technicians.

3 RESEARCH METHODOLOGY

3.1 DACUM-AMOD Method

The DACUM-AMOD method is a combination of the DACUM (Developing A Curriculum) method and the AMOD (A Model) method. DACUM is a highly cost-effective and efficient competency analysis technique that can quickly reflect the current situation and effectively develop a competency profile for a job or position, including duties and tasks. It provides an overview of the competencies required for a particular job. On the other hand, AMOD differentiates competency levels, which enhances the benefits of DACUM by deepening the analysis. It strengthens the focus on primary and secondary tasks and can also serve as a benchmark for evaluating abilities, learning, and assessment. It presents tasks and competencies in a sequence from the simplest to the most difficult (Norton, 1997, 1998).

The main elements targeted by the DACUM-AMOD method include "duties," "tasks," and "competencies." The process typically begins with an analysis conducted by leading industry enterprises, first considering the primary purpose of various positions within the occupation. It then examines what is required to achieve that purpose, breaking it down into competency elements and units. AMOD was developed by Adams in 1968 (Li, 1999), categorizing competencies into seven levels. This study, based on its research objectives, removes the first level of "basic competencies" and combines the fourth and fifth levels into "the ability to work independently and solve problems." The competencies are divided into five levels that follow a linear relationship, which are then used to check and assess competency levels (as shown in Table 1).

Table 1. Hierarchy of competency levels

Level	Description of competency level for performing tasks	Notes
5	Can work independently, solve problems, and lead others	
4	Can work independently and solve problems	
3	Can work independently on their own	Baseline
2	Needs regular supervision and assistance to work	
1	Needs continuous teaching and assistance from others	

To facilitate communication with experts and ensure smooth identification of levels, the third level is used as a reference (commonly known as the baseline) for mapping and identifying the competencies of other levels, either upwards or downwards. In other words, individuals must undergo an upward or downward assessment and recognition. For example, if a person's competency for a particular task is at level three, they must demonstrate competencies at levels four and five in sequence in order to "lead others" in performing the same task. In recent years, advanced countries have frequently adopted this approach, combining fuzzy logic techniques to construct competency maps, competency standards, and training blueprints when establishing job competencies for emerging industries (Chen & Pham, 2001; Norton, 1997, 1998; Wichowski, 2011; Vargas Zuñiga, 2004).

3.2 Fuzzy Delphi Technique

The traditional Delphi technique has certain limitations in its process, one of which is the vagueness of human experience and judgment. To address this issue, scholars have moved away from previous consensus theories and attempted to replace Boolean truth values with degrees of truth. This is achieved by using fuzzy numbers to represent the subjective uncertainty in human cognitive processes. These fuzzy numbers are derived from linguistic variables (subjective, uncertain semantic variables), which are then transformed into fuzzy numbers using appropriate mathematical models. This approach allows the technique to handle the fuzzy elements of human thinking and to inductively summarize the uncertain information identified by experts (Chen & Pham, 2001; Ma, Shao, Ma, & Ye, 2011; Murray, Pipino, & van Gigch, 1985). The aim is to resolve the ambiguity present in traditional Delphi techniques (Guo & Li, 2009; Wang & Chen, 2007; Zadeh, 1965). In practice, the geometric mean is used as a criterion for group decision-making to achieve statistically unbiased results and avoid the influence of extreme values. This approach enhances the accuracy of the selection process (Kaufmann & Gupta, 1991).

In past research, triangular fuzzy numbers have commonly been used as the basis for studies. For example, Ishikawa et al. (1993) integrated expert opinions into fuzzy numbers using cumulative frequency distributions and fuzzy integral concepts. They proposed the max-min method and fuzzy integration to predict project implementation schedules. In recent years, the "two triangular fuzzy numbers" method has been used in conjunction with the Fuzzy Delphi technique to integrate expert cognition, resulting in more rational and practical outcomes (Lee, 2009; Shahhosseini & Sebt, 2011; Yang, 2010). Since two triangular fuzzy numbers are less prone to compromise phenomena than single triangular fuzzy numbers, the grey zone validation method is used to test whether expert opinions converge (i.e., reach consensus) (Ma et al., 2011). Once convergence is reached, the geometric mean value of the expert consensus is calculated. This method is more rigorous, reasonable, and produces results that are more objective and practical compared to the geometric mean of traditional triangular fuzzy numbers. It has been widely applied in research areas such as competency identification. For example, Lee, Liu, Nan, Ting, and Chou (2007) applied it to identify key competencies in the biotechnology industry; Bai and Chen (2008) and Chen and Li (2011) used it for providing learning guidance and assessing student achievement; Guo and Lee (2009) applied it to explore the financial and economic professional capabilities of vocational high school teachers; and Yang (2010) used it for the education and training of cabin crew on safety and survival factors. Therefore, this study adopts the two triangular fuzzy numbers Fuzzy Delphi technique to integrate expert opinions and uses the grey zone validation method to check if expert opinions have converged (reached consensus), ensuring that the results are scientifically objective and practical for identifying the essential competencies required for entry-level engineers and technicians in the LED industry.

3.3 Steps for Two Triangular Fuzzy Delphi Technique Analysis

Step 1: Develop the fuzzy Delphi expert questionnaire

Based on the professional work competency catalog for entry-level engineers and technicians required in the LED lighting industry, developed through the DACUM-AMOD method, a structured fuzzy competency questionnaire was designed. Experts were invited to provide a possible range of values for each competency item to evaluate their opinions and determine whether the values were appropriate.

The range of values includes a minimum value C^i, a maximum value O^i, and a single value a^i. The minimum value represents the expert's "most conservative perceived value" for the competency item's score, the maximum value represents the "most optimistic perceived value," and the single value is the expert's "subjective best perceived value," also referred to as the expert value (subjective value).

Step 2: Collect group decision-making opinions

Each competency i was assessed, and statistical analysis was conducted on the C^i and O^i values provided by all experts. Extreme values outside of "two standard deviations" were excluded. Subsequently, the minimum values C_L^i、O_L^i、a_L^i, geometric mean values C_M^i、O_M^i、a_M^i, and maximum values C_U^i、O_u^i、a_U^i for the remaining C^i, O^i, and a^i values were calculated separately.

Step 3: Establish fuzzy two-triangular functions

Triangular fuzzy numbers were separately established for each competency evaluation item i based on the C^i and O^i values calculated in Step 2. The triangular fuzzy numbers for C^i and O^i are represented as $C^i = (C_L^i, C_M^i, C_U^i)$, and $O^i = (O_L^i, O_M^i, O_U^i)$, as shown in Figure 2.

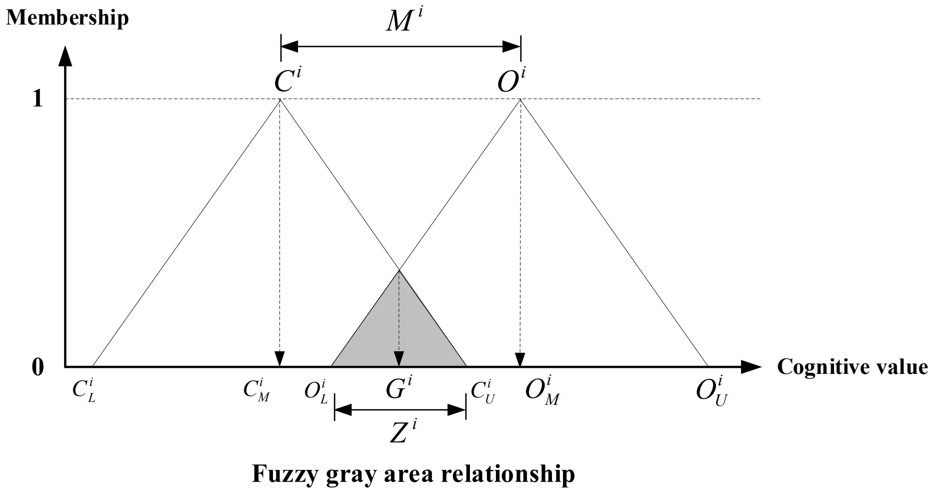

Figure 2. Two triangular Fuzzy Delphi technique.

Source: Based on Yang (2010), pp. 38

Step 4: Use of the "grey zone validation method" to identify competency dimensions

1. No grey zone present

If $(C_U^i \leq O_L^i)$, meaning the dual-triangular fuzzy numbers do not overlap, it indicates that the expert opinion ranges have reached a consensus, and the opinions are converging within the consensus region. Therefore, the consensus importance level value G^i for this competency evaluation item i is defined as the arithmetic mean of C_M^i and O_M^i: $G^i = (C_M^i + O_M^i)/2$ (1)

2. Grey zone present, but small discrepancy in expert opinions

If $(C_U^i > O_L^i)$, an overlap occurs between the double triangular fuzzy numbers, but the gray area of the fuzzy relationship, $Z^i = C_U^i - O_L^i$, is smaller than the interval range $M^i = O_M^i - C_M^i$ between the geometric mean of the experts' optimistic perception O^i and the geometric mean of their conservative perception C^i for the competency assessment item. In other words, $Z^i < M^i$ which indicates that while there is no consensus range among the experts' opinion intervals, the experts who provided extreme values do not significantly differ from the others, preventing a divergence of opinions. Therefore, the consensus importance value G^i for this competency assessment item i is set equal to the fuzzy set $F^i(x_j)$, obtained by performing the intersection (min) operation on the double triangular fuzzy numbers. The quantized score is then derived from the fuzzy set with the maximum membership degree $u_{F^i}(x_j)$.

$$F^i(x_j) = \left\{ \int_x \left\{ \min\left[C^i(x_j), O^i(x_j) \right] \right\} dx \right\} \tag{2}$$

$$G^i = \left\{ x_j \middle| \max \mu_{F^i}(x_j) \right\} \tag{3}$$

3. Grey zone present, with large discrepancy in expert opinions

If $(C_U^i > O_L^i)$, meaning $Z^i > M^i$, this indicates that there is no consensus region in the expert opinion ranges, and the opinions of experts who provided extreme values differ significantly from those of other experts, resulting in divergent opinions. Therefore, these non-convergent competency evaluation items should be excluded. However, this phenomenon did not occur during the implementation of this study.

Step 5: Define the "threshold value" to identify competency dimensions for entry-level engineers and technicians in the LED lighting industry

The definition of the threshold value S will affect the identified competency items. This study takes into account the overall structure of the competency catalog required for entry-level engineers and technicians in the LED lighting industry, as well as the appropriateness of the expert group selection. In filtering the threshold value, the first step is to measure the more objective consensus importance level G^i provided by each expert for the competency items. Next, the more subjective a^i values are assessed to determine which competencies are considered essential for entry-level engineers and technicians in the LED lighting industry, and which are not deemed essential. The process is as follows:

1. When $G^i \geq S$ and $a^i \geq S$ are present, it indicates that x_j is an important competency item.
2. When $G^i < S$ and $a^i < S$ are present, it indicates that x_j is a less important competency item.

3.4 Implementation Method

Step 1: Research process

The research process consists of four stages, as shown in Figure 3. In the first and second stages, qualitative expert discussions and the DACUM-AMOD method are used to gather first-hand data from experts and identify the competencies required for entry-level engineers and technicians in the LED lighting industry. The third and fourth stages use quantitative questionnaire assessments, with the fourth stage applying the fuzzy Delphi technique's grey zone validation method to further identify the competencies needed for entry-level engineers and technicians in the LED lighting industry.

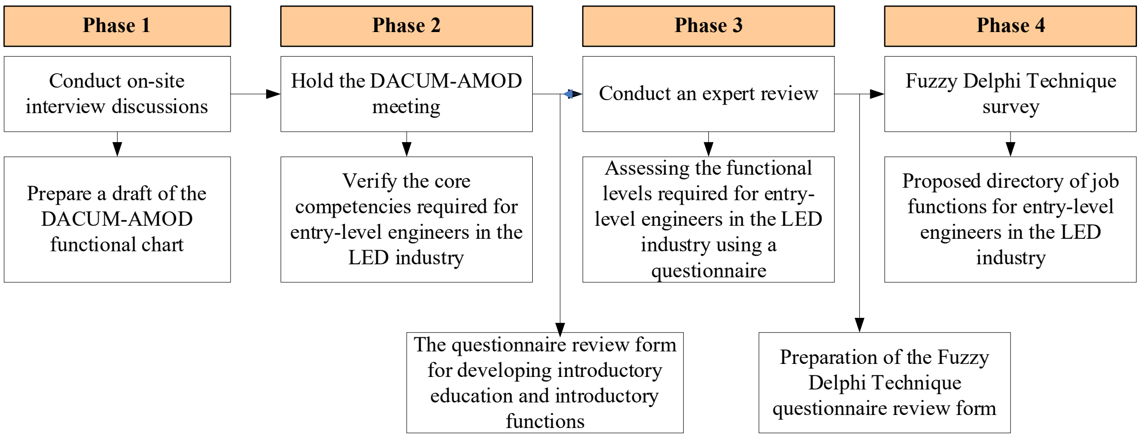

Figure 3. Research process flowchar

Step 2: Implementation stage

In selecting industry experts, the company uses "purposive sampling" by consulting publicly listed companies. The selection criteria are based on factors such as the company's establishment time, capital, and profitability, ensuring a certain level of representativeness. Experts must have at least a university degree and experience in LED-related research and development, design, production, and manufacturing. They should also have a solid track record in the field, with a minimum of three years of practical experience. Additionally, they must possess a sufficient understanding of the research topic and be willing to fully cooperate during the investigation period. The list includes representatives from the upstream, midstream, and downstream sectors of the LED lighting industry.

The first phase involves inviting experts and holding meetings. The deputy director of the R&D department of a listed company and the manager of an LED packaging plant were invited. The expert meetings and on-site interviews clarified the tasks and competencies developed during the literature review phase, created a draft of the technical competencies, and identified the responsibilities and tasks required by the industry for recruiting new graduates with a university degree.

The second phase involves the DACUM-AMOD meeting, which invited six experts from five listed companies in the upstream, midstream, and downstream sectors. This meeting revealed that the upstream sector includes epitaxial and crystal grain production, the midstream sector focuses on package, and the downstream sector deals with lighting products. Experts across all tiers discussed R&D/design, manufacturing, and analysis (including quality assurance, measurement, and market applications), resulting in: (1) 25 responsibilities and 78 tasks; (2) the industry is moving towards upstream integration, and downstream talent must possess upstream knowledge; (3) employers consider whether applicants have deeply studied relevant courses during their university education; and (4) the required skills vary across different tiers of high-end talent in the industry.

The third phase involves expert review, which assesses content validity. Seven industry experts evaluated the importance of each competency. This phase resulted in 25 responsibilities, 78 tasks, and 303 competencies. Regarding the number of experts required for evaluation, Norton (1998) suggested that a group size of 5 to 12 experts is optimal for minimizing group error and maximizing reliability, which aligns with this study's approach.

The fourth phase involves a fuzzy Delphi method questionnaire survey, where important competencies are selected through expert group decision-making. After the researcher reviewed the face validity of the fuzzy Delphi method questionnaire, it was confirmed by 10 LED lighting industry experts. The results included 25 responsibilities, 77 tasks, and 299 competencies. The sample selection for the questionnaire was based on the following criteria to determine its validity: (1) candidates with at least three years of experience; (2) respondents who provided complete answers; and (3) respondents whose answers demonstrated clear consistency and varying degrees of strength.

Step 3: Data analysis and processing

(1) Handling extreme values outside of "Two Standard Deviations"

After analyzing the 303 competencies for entry-level engineers and technicians, 4 items were removed, leaving 299 items. The overall responsibilities were then consolidated, reducing the original 25 responsibilities, 78 tasks, and 303 competencies to 25 responsibilities, 77 tasks, and 299 competencies.

(2) Threshold indicators for each field

The fuzzy Delphi method questionnaire evaluation used a 1 to 10 scale, with higher scores indicating greater importance and stronger demand. The values entered were determined subjectively based on the experts' professional knowledge. The purpose was to identify the importance level of job competencies for entry-level engineers and technicians in the industry. The gray zone testing method of double triangular fuzzy numbers is used to examine the more objective consensus importance value G^i and the more subjective value a^i provided by each expert (Bai & Chen, 2008; Chen & Li, 2011; Guo & Li, 2009; Shahhosseini & Sebt, 2011; Yang, 2010). The more objective threshold value G^i, after the test calculation is: epitaxial (6.50), crystal grain (6.70), package (7.28), and lighting products (7.14). a^i values were: epitaxial (6.77), crystal grain (7.28), package (7.85), and lighting products (7.63). Whether it is the more objective G^i value of the interval or the more subjective a^i value provided by the experts, the focus remains consistent, emphasizing the concrete consensus among the experts. The importance of these values reflects the level of competence required for entry-level engineers and technicians in the industry, as well as serving as a key indicator of the industry's competitiveness in the international market.

4 RESULTS AND DISCUSSION

4.1 Important Competencies in The Epitaxy Field

Based on the competency analysis of various tasks in the epitaxy field, 8 tasks are considered important ($G^i \geq 6.50$ and $a^i \geq 6.77$). These tasks, in order of importance, are: A11: Development of advanced technologies, C21: Analyze patents, C23: Avoid patents B32: Improve yield, C22: Apply for patents, B11: Design and improve MOCVD equipment, C12: Measure epitaxial material characteristics, A22: Select, measure, and analyze epitaxial materials (as shown in Table 2).

Table 2. Responsibilities and tasks in the epitaxial field

Fields	**Responsibilities**	**tasks**	G^i	a^i	**Sort (G^i)**
A. R&D	A1 Material development	A11 Develop advanced technologies	7.26	7.75	1
		A12 Develop epitaxial materials	6.34	6.75	11
	A2 Structural design	A21 Simulate epitaxial optoelectronic properties	6.43	6.69	10
		A22 Select, measure, and analyze epitaxial materials	6.54	6.90	8
B. Manufacturing	B1 Equipment development	B11 Design and improve MOCVD equipment	6.76	6.79	6
		B12 Develop tools for automating MOCVD equipment	6.08	5.85	14
	B2 Equipment maintenance	B21 Maintain MOCVD equipment	6.19	6.10	12
		B22 Maintain epitaxy-related equipment	5.89	5.96	16
	B3 Manufacturing process	B31 Analyze data	6.49	6.51	9
		B32 Improve yield	6.93	6.94	4
		B33 Write MOCVD equipment programs and operations	5.64	5.44	17
		B34 Simplify manufacturing processes	6.15	6.40	13
C Analysis	C1 Quality	C11 Analyze epitaxial material characteristics	6.00	6.77	15
		C12 Measure epitaxial material characteristics	6.70	7.23	7
	C2 Patent layout	C21 Analyze patents	7.21	7.87	2
		C22 Apply for patents	6.83	7.48	5
		C23 Avoid patents	7.16	8.11	3
		Threshold value	**6.50**	**6.77**	

Note: In the table, the cells with a white background in the G^i and a^i value columns represent greater importance, while the shaded cells indicate lesser importance.

The entry-level education required for these important tasks is a master's degree, with the competency levels required as follows: 9 tasks at level 2, 9 tasks at level 3, and 11 tasks at level 4. The tasks related to important competencies in the epitaxy field are heavily concentrated in the "C Analysis" category, such as C12 (Measure epitaxial material characteristics), C21 (Analyze patents), C22 (Apply for patents), and C23 (Avoid patents) (as shown in Appendix 1: Detailed List of Important Competencies for Responsibilities and Tasks in the Epitaxial Field).

4.2 Important Competencies in The Crystal Grain Field

Based on the competency analysis of various tasks in the crystal grain field, 7 tasks are considered important ($G^i \geq$ 6.70 and $a^i \geq$ 7.28). These tasks, in order of importance, are: C23: Avoid patents, C21: Analyze patents, A12: Develop crystal grain component materials, B22: Improve yield, A11: Development of crystal grain component technology, C22: Apply for patents, B21: Analyze data (as shown in Table 3).

Table 3. Responsibilities and tasks in the crystal grain field

Fields	**Responsibilities**	**Tasks**	G^i	a^i	**Sort** (G^i)
A R&D	A1 Crystal grain component development	A11 Development of crystal grain component technology	6.95	7.74	5
		A12 Develop crystal grain component materials	7.25	7.93	3
	A2 Crystal grain component design	A21 Simulate crystal grain component optoelectronic properties	6.01	6.50	13
		A22 Select (measure and analyze) crystal grain component materials	6.52	6.88	11
B Manufacturing	B1 Equipment maintenance	B11 Evaluate crystal grain equipment	6.56	7.02	10
		B12 Maintain crystal grain equipment	5.86	5.82	14
	B2 Manufacturing	B21 Analyze data	6.89	7.63	7
		B22 Improve yield	6.97	7.95	4

Fields	Responsibilities	Tasks	G^i	a^i	Sort (G^i)
	process	B23 Operate crystal grain equipment	5.57	5.80	15
		B24 Simplify manufacturing processes	6.46	6.98	12
C Analysis	C1 Quality	C11 Analyze crystal grain material characteristics	6.69	7.27	8
		C12 Measure crystal grain material characteristics	6.68	7.30	9
	C2 Patent layout	C21 Analyze patents	7.38	8.13	2
		C22 Apply for patents	6.91	7.62	6
		C23 Avoid patents	7.39	8.11	1
		Threshold value	**6.70**	**7.28**	

Note: In the table, the cells with a white background in the G^i and a^i value columns represent greater importance, while the shaded cells indicate lesser importance.

The entry-level education required for these important tasks is a master's degree, with the competency levels required as follows: 6 tasks at level 2, 13 tasks at level 3, and 9 tasks at level 4. As with the epitaxy field, the tasks related to important competencies in the chip field are also concentrated in the "C Analysis" category, such as C21 (Analyze patents), C22 (Apply for patents), and C23 (Avoid patents) (as shown in Appendix 2: Detailed List of Important Competencies for Responsibilities and Tasks in the Crystal Grain Field).

4.3 Important Competencies in The Package Field

Based on the competency analysis of various tasks in the package field, 10 tasks are considered important ($G^i \geq 7.28$ and $a^i \geq 7.85$), listed in the following order: B22: Improve yield, A21: Develop coating technology, C21: Analyze patents, A33: Simulate package optoelectronic and thermal characteristics, B21: Analyze data, C22: Apply for patents and avoid patent, C12: Evaluate component reliability, B24: Simplify manufacturing processes, A11: Develop package substrate materials, A32: Design package structures (as shown in Table 4).

Table 4. Responsibilities and tasks in the package field

Fields	**Responsibilities**	**Tasks**	G^i	a^i	**Sort** (G^i)
A R&D	A1 Package material development	A11 Develop package substrate materials	7.33	7.95	9
		A12 Develop adhesive materials	7.07	7.64	18
		A13 Develop phosphor materials	7.26	7.81	13
	A2 Package technology development	A21 Develop coating technology	7.73	8.50	2
		A22 Develop dot dispensing technology	7.11	7.75	17
		A23 Develop flip-chip technology	7.24	7.64	15
	A3 Package design	A31 Design package optics	7.26	7.75	14
		A32 Design package structures	7.31	7.87	10
		A33 Simulate package optoelectronic and thermal characteristics	7.66	8.33	4
		A34 Select (measure and analyze) package materials	6.71	6.92	20
B Manufacturing	B1 Equipment maintenance	B11 Evaluate package equipment	7.28	7.74	12
		B12 Develop package equipment	6.85	7.49	19
		B13 Maintain package equipment	6.62	7.16	21
	B2 Manufacturing process	B21 Analyze data	7.60	8.27	5
		B22 Improve yield	8.35	9.01	1
		B23 Operate package equipment	6.48	6.60	22
		B24 Simplify manufacturing processes	7.34	8.27	8
C Analysis	C1 Quality	C11 Analyze package component characteristics	7.28	7.80	11
		C12 Evaluate component reliability	7.36	8.22	7
		C13 Measure package component characteristics	7.12	7.62	16
	C2 Patent layout	C21 Analyze patents	7.71	8.14	3
		C22 Apply for patents and avoid patent	7.40	7.92	6
		Threshold value	**7.28**	**7.85**	

Note: In the table, the cells with a white background in the G^i and a^i value columns represent greater importance, while the shaded cells indicate lesser importance.

The required entry-level education includes 6 tasks that demand a master's degree and 4 tasks that require a bachelor's degree. The competency level required for entry is as follows: 4 tasks at level 1, 22 tasks at level 3, and 16 tasks at level 4. The tasks related to important competencies in this field primarily focus on the "A R&D" area, including A11 (Develop package substrate materials), A21 (Develop coating technology), A32 (Design package structures), and A33 (Simulate package optoelectronic and thermal characteristics) (as shown in Appendix 3: Detailed List of Important Competencies for Responsibilities and Tasks in the Package Field).

4.4 Important Competencies in The Lighting Product Field

In the lighting product field, 13 tasks are considered important ($G^i \geq 7.14$ and $a^i \geq 7.63$), listed in the following order: A15: Conduct thermal design, B22: Improve yield , C12: Evaluate lighting product reliability, C23: Avoid patents, C13: Evaluate lighting product safety, A19: Integrate optomechanical design, C22: Apply for patents, C21: Analyze patents, C11: Analyze lighting product characteristics, A16: Conduct circuit design, A13: Conduct optical design, C14: Measure lighting product characteristics, B21: Analyze data (as shown in Table 5).

Table 5. Responsibilities and tasks in the lighting product field

Fields	**Responsibilities**	**Tasks**	G^i	a^i	**Sort** **(**G^i**)**
A R&D	A1 Lighting product design	A11 Conduct human factor engineering	7.08	7.58	16
		A12 Conduct industrial design	6.85	7.40	20
		A13 Conduct optical design	7.25	7.78	11
		A14 Conduct spatial lighting design	6.89	7.50	19
		A15 Conduct thermal design	7.53	8.11	1
		A16 Conduct circuit design	7.28	7.91	10
		A17 Conduct mechanical design	6.96	7.49	17
		A18 Ensure safety standards and certification	7.17	7.59	14
		A19 Integrate optomechanical design	7.46	7.74	6
B	B1 Equipment	B11 Evaluate SMT equipment	7.10	7.34	15

Fields	Responsibilities	Tasks	G^i	a^i	Sort (G^i)
Manufacturing	maintenance	B12 Develop SMT automation equipment	6.60	7.34	21
		B13 Maintain SMT equipment	6.50	6.92	22
	B2 Manufacturing process	B21 Analyze data	7.19	7.97	13
		B22 Improve yield	7.52	8.12	2
		B23 Operate SMT equipment	5.88	5.76	23
		B24 Simplify manufacturing processes	6.93	7.46	18
C Analysis	C1 Quality	C11 Analyze lighting product characteristics	7.36	7.75	9
		C12 Evaluate lighting product reliability	7.51	8.26	3
		C13 Evaluate lighting product safety	7.46	7.87	5
		C14 Measure lighting product characteristics	7.22	7.64	12
	C2 Patent layout	C21 Analyze patents	7.43	7.90	8
		C22 Apply for patents	7.45	7.73	7
		C23 Avoid patents	7.49	8.20	4
		Threshold Value	**7.14**	**7.63**	

Note: In the table, the cells with a white background in the G^i and a^i value columns represent greater importance, while the shaded cells indicate lesser importance.

The required entry-level education includes 6 tasks that demand a master's degree and 7 tasks that require a bachelor's degree. The competency levels for entry are as follows: 8 tasks at level 1, 2 tasks at level 2, 24 tasks at level 3, 12 tasks at level 4, and 3 tasks at level 5. The tasks related to important competencies in this field primarily focus on the "C Analysis" area, including C11 (Analyze lighting product characteristics), C12 (Evaluate lighting product reliability), C13 (Evaluate lighting product safety), C14 (Measure lighting product characteristics), C21 (Analyze patents), C22 (Apply for patents), and C23 (Avoid patents) (as shown in Appendix 4:

Detailed List of Important Competencies for Responsibilities and Tasks in the Lighting Product Field).

4.5 Research Limitations

Through empirical procedures, this study identified 25 responsibilities, 77 tasks, and 299 competencies in the advanced LED lighting industry, with the results demonstrating significant reliability and validity. However, the study has certain limitations. First, the LED expert meetings and the fuzzy Delphi questionnaire survey were based on a purposive sample of publicly listed companies, meaning the findings may not be generalizable to non-listed companies. Second, when addressing extreme values beyond "two standard deviations," only 4 items were excluded, leaving 45 items, based on the continuity and inclusiveness of responsibilities and tasks. Additionally, key tasks such as "B11 Design and Improvement of MOCVD Equipment" and "B32 Improve Yield" in upstream epitaxy, which are crucial competencies, were retained. Further investigation, analysis, and verification of this area are necessary.

5 CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

This study used expert meetings, brainstorming methods through DACUM-AMOD, questionnaire reviews, fuzzy Delphi techniques, and the dual-triangle fuzzy gray area test method to identify the professional competencies required for entry-level engineers and technicians in the LED lighting industry. The results provide a detailed "Catalog of Professional Competencies Required for Entry-level Engineers and Technicians in the LED Lighting Industry," which can be used as a reference by domestic training organizations. It also serves as a guide for engineering and technology departments in universities to develop training or curriculum for talent development.

The unique nature of the LED lighting industry is evident in its segmentation into four major areas: epitaxial, crystal grain, package, and lighting products. These areas correspond to upstream, midstream, and downstream sectors, with the upstream industry requiring workers with higher educational qualifications. Regarding entry-level education, the epitaxial and crystal grain sectors generally require a master's degree. The packaging sector has 6 important tasks that require a master's degree for entry-level engineers or technicians, and 4 that require a bachelor's degree. In lighting products, 6 important tasks require a master's degree, and 7 require a bachelor's degree.

It can be concluded that industries demanding direct labor (such as manufacturing, equipment, or plant operations) mostly require bachelor's degrees or lower, while indirect labor (such as process, quality assurance, or sales) generally requires bachelor's degrees or higher. R&D positions typically require a master's degree or higher. In particular, important tasks in epitaxial, crystal grain, and lighting products tend to focus on the "C Analysis" area, primarily using patent analysis to enhance market competitiveness and improve R&D and process capabilities. On the other hand, packaging focuses more on the "A R&D" area, emphasizing the development of packaging materials, packaging technologies, and packaging design.

The entry-level competency levels are primarily concentrated at Level 3, "Able to work independently," with a total of 68 items, distributed as follows: 9 items in epitaxial, 13 in crystal grain, 22 in package, and 24 in lighting products. The next most frequent is Level 4, "Able to work independently and solve problems," with 48 items: 11 in epitaxial, 9 in crystal grain, 16 in package, and 12 in lighting products. The third most frequent is Level 2, "Requires regular supervision and assistance to work," with 17 items: 9 in epitaxial, 6 in crystal grain, and 2 in lighting products. The fourth is Level 1, "Requires constant supervision and assistance to work," with 12 items: 4 in package and 8 in lighting products. Finally, the highest entry-level competency, Level 5, "Able to work independently, solve problems, and lead others," is required for 3 competencies in the lighting product task "A16 Circuit Design." This highlights the trend that the higher the industry level (upstream sectors), the higher the educational qualifications required. It also underscores the industry's demand for entry-level workers with a university degree or higher, particularly those with Level 3 and Level 4 competencies.

The 25 responsibilities, 77 tasks, and 299 competencies for entry-level engineers and technicians in the LED lighting industry, developed in this study, can assist various sectors, including industry, government, academia, and research. Specifically, by identifying the required entry-level educational qualifications and competency levels in the LED lighting industry, this catalog can help calibrate talent development and recruitment specifications. It addresses the gap between the supply and demand of competencies, ensuring an adequate talent supply to meet industry needs. This is crucial for the next phase of international competition in LED lighting industry. Both the quantity and quality of talent development are expected to help foster the industry to become a global leader. Therefore, the competencies developed in this study can serve as a benchmark for formal education and a reference for informal learning.

5.2 Suggestions

Currently, domestic companies face a gap in both the availability and quality of talent. This issue arises not only from the supply-demand imbalance in the job market but also from the fact that industry employers value not only academic qualifications but also competencies. They expect university graduates to be immediately ready to contribute, minimizing the need for retraining. As competencies act as the "interface between the labor market and the education system," advanced countries are increasingly paying attention to the talent needs of the emerging LED lighting industry. To maintain or even enhance corporate competitiveness and organizational capability, higher competency standards for entry-level positions are required, especially when competencies are seen as core to organizational knowledge, employee skills, attitudes, and corporate competitiveness.

This study's catalog of competencies for entry-level engineers and technicians in the LED lighting industry primarily focuses on the early stages of the value chain, such as R&D, innovation, design, and manufacturing departments. Curriculum planning and design should particularly focus on these areas to ensure that graduates are capable of meeting the high-end needs of the LED lighting industry. Since the study predominantly used a purposive sampling of listed companies, future research could adopt other methods or compare results from different approaches, especially with regard to small and medium-sized enterprises in the LED lighting sector. Furthermore, important competencies in the LED lighting industry may evolve in response to industry demands, so it is essential to periodically review and adjust them according to environmental changes.

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