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An extended Fuzzy-AHP approach to rank the influences of socialization-externalization-combination-internalization modes on the development phase

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ABSTRACT

Continuous innovation intended to deliver products with new attributes is an imperative driver for organizations to remain competitive in today's fast changing market. A successful innovation is often associated with adoption and execution of all SECI (socialization-externalization-combination-internalization) modes of knowledge creation within any Product Development (PD) phase. This article is an attempt to argue with the general notion and to distinguish different PD phases' affinity corresponding to distinct SECI modes. In this regard, the paper proposes an extended Fuzzy Analytic Hierarchy Process (EFAHP) approach to determine the ranking in which any PD phase is influenced from SECI modes. In the EFAHP approach, the complex problem of knowledge creation is first itemized into a simple hierarchical structure for pairwise comparisons. Next, a triangular fuzzy number (TFN) concept is applied to capture the inherent vagueness in linguistic terms of a decision-maker. This paper recommends mapping TFNs with normal distributions about X-axis. This allows us to develop a mathematical formulation to estimate the degree of possibility (importance value) when two TFNs do not intersect with each other (current techniques in literature calculate this value as zero). In order to demonstrate the applicability and usefulness of the proposed EFAHP in ranking SECI modes, an empirical study of development phase is considered. Five criteria and their 19 sub-criteria for measuring the phase's performance are identified based on both an extensive discussion with subject matter experts and rigorous literature survey. After stringent analysis, we found that the mode that highly influenced the development phase is 'combination mode'. The article discusses the application of lean tools that can be employed to improve the knowledge creation process.

1. Introduction

Capturing, sorting, storing and retrieving information from IT applications are widely discussed topics in the product development (PD) projects [1,7,15]. These IT applications essentially offer the advantages of dealing with the existing explicit knowledge. Naturally, increased internal efficiency can be associated with such initiatives. But, both academia and practitioners consider new knowledge creation as a key source of growth and an imperative tool to maintain the sustainable competitive advantage [1]. Traditional systems have a trivial impact on innovation due to the absence of any process and/or tool for knowledge creation [2,3]. This is due to the fact that one can't solve new and unfamiliar problems with the existing old knowledge. An employee is required to possess new knowledge creation ability. Therefore, exploring methods intended to assist employees in performing tasks excellently by creating and enabling new knowledge is a modern challenge faced by many organizations [4]. An important question that needs to be asked here is "*is there any theory which can be applied to knowledge creation?*" This question has resulted in development and adoption of various models and best practices to represent the processes pertaining to knowledge creation. This paper primarily targets the SECI model of knowledge creation presented by Nonaka [5]. In the model, the processes of interplay between tacit and explicit knowledge are categorized into four modes. These four modes referred with the acronym SECI are Socialization (tacit to tacit), Externalization (tacit to explicit), Combination (explicit to explicit), and Internalization (explicit to tacit).

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All SECI modes are conceptually linked and utilized within distinct PD phases with a view to improve the performance of end product [6–9]. This article challenges this conventional assumption that all SECI modes affect a PD phase. If there is an effect, can all the four SECI modes be assumed to have a positive influence on improving the performance, is a question that still needs to be investigated. Extensive literature review clearly indicates that a very limited work has been done on this topic and therefore a research gap exists. This article is an attempt to bridge the gap.

As mentioned earlier, this article challenges the fundamental approach of '*correlating all SECI modes with each PD phase*'. This is due to the fact that selection of appropriate SECI mode can significantly affect the efficiency of the strategic planning and help in saving the business resources. In this context, SECI modes are explained as a foundation of knowledge creation. Subsequently, in order to rank SECI modes influence on development phase, an extended Fuzzy Analytic Hierarchy Process (EFAHP) approach is proposed. The EFAHP embeds the merits of fuzzy set theory into a decision making tool (AHP). AHP develops a hierarchy system and takes experts opinions into account in scoring the alternatives. The hierarchical structure approach requires identifying critical criterion and sub-criterion. Identification of an appropriate set of criteria and sub-criteria to compare SECI modes is a cumbersome task. This article utilizes the knowledge and information collected from subject matter experts (SMEs) and a rigorous review of available literature in the respective areas. This article identifies top five criteria that play a key role in providing the insights, evaluating and then comparing SECI modes during the development phase. The criteria are further decomposed into 19 sub-criteria for proper handling of the underlying problem. These criteria and sub-criteria can be selected based on preferences of organizations, thus making it an adaptive solution that fits their needs.

In EFAHP approach, evaluation employs the pairwise comparison of two triangular fuzzy numbers (TFNs) developed from the linguistic preferences of a decision-maker. In such evaluation, the height of ordinate estimated from the intersection point of two TFNs is utilized to calculate the degree of possibility of one criterion over another [10–12]. If two TFNs are not intersecting, the corresponding value of degree of possibility is assumed to be zero [13]. The situation (two triangles are not intersecting) represents the case of one criterion being stronger than other and should not receive a zero value. This paper proposes to map the triangle edges with a normal distribution about X-axis. This allows developing a mathematical formulation to estimate the values of height of ordinate (degree of possibility) instead of setting it zero. Thus, EFAHP provides an opportunity to efficiently rank the alternatives by acting as an expert evaluation system.

The remainder of this paper is organized as follows: the next section reviews the relevant literature of knowledge creation, AHP and fuzzy logic. Highlights of SECI model are given in section III. Section IV provides the rationale behind selecting each criterion. Section V details implementation of proposed EFAHP as a strategic decision making tool. Obtained results and their discussion with expected benefits are summarized in section VI. Section VII offers the lean tools that can support the new knowledge creation for combination mode. Finally, section VIII summarizes the entire paper and provides the direction for future research.

2. Literature review

Knowledge is what one already knows, and practice of making it instantaneously available in a usable format to create value is knowledge management. Knowledge management has been the core focus of research and the vast literature primarily targeted on how to locate, store, or share the knowledge for internal competitive advantage [14–17]. However, research papers drawing attention on opportunities and limitations of knowledge creation are comparatively very low. Knowledge creation is defined as the process of continuously updating or increasing the knowledge base of what one knows now than what one didn't know before and keeping it accessible, and usable. The basic difference between knowledge management and knowledge creation is that former helps in filling the gaps to complete raw data/information but later actually assists in problem solving. Alavi and Leidner [15] asked interesting questions related to conditions that facilitate knowledge creation, and incentives that encourage knowledge contribution for effective knowledge transfer. Goffin and Koners [18] supported that interactions and actions among internal and external knowledge resources can be leveraged to create knowledge. With this regard, state-of-art SECI model is considered as most influential and is universally accepted. The details of the model are discussed in section III.

Few works analyzed the SECI model from knowledge management perspectives in PD environment. Pitt and Clark [7], Chatenier et al., [8], Hammad and Nikolaos [9], and Krogh et al., [19] conceptually linked innovation with dynamic knowledge, but they failed to provide detailed concepts and any empirical evidences. Existing empirical studies have targeted issues in domains other than development phase, such as knowledge creation during idea generation [20], solving technical problems [21], networking influences on knowledge creation [22,23] etc. Madhavan & Grover [1] and Schulze & Hoegl [24] compared SECI modes within PD phases and advocated its importance in analysis of performance improvement. This research is built upon the work conducted by Schulze & Hoegl [24] where they developed and tested the hypotheses to relate the product success with SECI modes performed during concept and development phases. They found that PD success is positively influenced by socialization during the concept phase and combination during the development phase. However, their research did not incorporate any subjective criteria during analysis, hence constraining conclusions to a particular organization.

This paper proposes to use subjectivity and freedom in choosing criteria and sub-criteria for evaluation, making it a Multi-criteria Decision Making (MCDM) problem. Keeping this in mind, Thomas L. Saaty introduced a simple yet systematic Analytic Hierarchy Process (AHP) method. It is a useful, and practical method and has been used as a tool for weight estimation in deriving valid argumentative decisions for machine selection in flexible manufacturing system [25], resource allocation by prioritizing information [26], supplier selection [10,27], reverse logistics and product recovery [28], selection of innovative educational project [29] etc.

AHP is fundamentally built on two basic concepts: 1) formulation of the problem in a hierarchical structure, and 2) use of pairwise comparison. Hierarchical formulation breaks down the general or uncontrollable criteria into more particular or controllable ones. The criterions are subjected to a pairwise comparison to assign weights from a scale of 1–9. These absolute scale numbers (1–9) transforms the human preferences between available alternatives as equally, moderately, strongly, very strongly or extremely important to decide their resulting priorities. AHP is a better fit for prioritizing the alternatives based on numerical scales when ideas, feelings, and emotions play a role in decision-making process. The central theme of AHP accounts for expert's opinion, subjective judgments, and pReferences

Despite obvious advantages, AHP is not free from inherent pitfall as pointed out in recent publications [30–32]. Decision-making approximates vague human judgments in form of crisp values such as 1 or 3 [10,32]. The shortcoming of AHP is related with assumption of certainty in assessing the relative importance of criterions because real world decision problems are vague. The decision-maker often feel difficulty in assigning crisp numerical values for uncertain human preferences [10]. Hence, need of adequately handling the inherent uncertainty and vagueness in mapping the individual's perception to exact numbers arises. In order to bridge this gap, fuzzy set theory was introduced into AHP [33]. Fuzzy set theory, developed by Zadeh [34], mathematically represents the human judgments to capture impreciseness and vagueness of the approximate information. It resembles human reasoning in incorporating unquantifiable, uncertain information and partial facts into decision model. It can effectively handle uncertainty by fuzzy evaluations matching with the variations in decision-maker's input information [35,36]. A fuzzy set is characterized by a membership function (Eq.(1)) to calculate the membership value (λ).

$$\lambda\left(\alpha|\tilde{T}\right)=\begin{bmatrix}\dfrac{(\alpha-t_1)}{(t_2-t_1)} & (t_1\leq\alpha\leq t_2)\\ \dfrac{(t_3-\alpha)}{(t_3-t_2)} & (t_2\leq\alpha\leq t_3)\end{bmatrix} \tag{1}$$

Where, t_1, t_2, and t_3 represent the smallest possible value (pessimistic), the most promising value and the largest possible value (optimistic) for a fuzzy set. These three point estimates are converted into triangular distribution. These triplets form a triangular fuzzy number (TFN) of a fuzzy set which is illustrated by putting '∼' on letter T (called as *about T*).

Van-Laarhoven and Pedrycg [33] utilized TFNs and obtained the priority vectors using logarithmic least squares method. Chang [12] introduced a mathematical formulation for extent analysis approach to estimate the synthetic extent values of the pairwise comparisons and the degree of possibility when $(t_{11}- t_{23}) \leq 0$. The mathematical formulation primarily takes into account the ordinate of highest intersection point of two TFNs (see Eq. (9)). However, if $(t_{11}- t_{23}) \geq 0$ (when two TFNs don't intersect), the values are taken normalized (see Chang [12] on page 653). Zhu et al. [13] extended it and provided a proof that if $(t_{11}- t_{23}) \geq 0$ (see Fig. 3), then value of degree of possibility should be zero. Further, Wang et al., [37] criticized this 'zero' value approach since this method was found unable to derive the true weights (for fuzzy or crisp comparison). They also concluded that extent analysis method does not estimate the correct relative importance of decision criteria and hence of alternatives. The authors of this article also agree with the conclusion of Wang et al. [37]. A zero value approach can result in zero priority weight to a criterion (alternative) in the extent analysis method. This omits that particular criterion or alternative from further decision-making analysis. If that is the case, then the criterion or alternative should not be included while developing the comparison matrix in the start. During our analysis (see Section VI), it was found that the two TFNs do not intersect because one criterion or alternative is highly important than the other and should not receive a zero weight. This paper introduces an approach to estimate the true degree of possibility based on mapping of a TFN by a normal distribution with respect to X-axis until they intersect. Best to our knowledge from comprehensive literature review, this is the first attempt to propose such implementation of an extended Fuzzy-AHP.

3. Seci model of knowledge creation

According to Nonaka [5], knowledge is divided into two types: explicit knowledge and tacit knowledge. Explicit knowledge can be presented in form of a code, language, and written reports using data, scientific formulae, and manuals and can be communicated, processed, transmitted and stored relatively easily. On the other hand, tacit knowledge refers to a knowledge which is only known by an individual. It is personal knowledge embodied in actions, attitude, commitment, emotions and behavior and difficult to codify to communicate in a 'language'. It can only be learned by sharing experiences, observation and imitation [38]. Facts and theories i.e. 'knowing-about' fall under the category of explicit knowledge whereas skills to perform any job ('knowing-how') are in the helms of tacit knowledge. It is very difficult for anyone to learn and develop 'know-how' skills just by reading or by watching audio/video media. The individual has to indulge in hands-on activities in order to gain tacit knowledge. Among the two, tacit knowledge is more important due to its contribution towards continuous innovation and takes a larger portion of existing knowledge. Additionally, competence in form of tacit knowledge embodying in the heads of employees ultimately defines the strength of an organization.

Though tacit knowledge is a source of competitive advantage, it quickly loses it meaning without the explicit knowledge. They complement each other and absence of one undermines the power of other. Krogh et al., [19] stated that their (tacit and explicit) interaction is immensely required to create new knowledge. The possible four-stage spiral model abbreviated as SECI is used to depict four separate knowledge conversion modes. The beginning point of spiral is socialization where exchange of tacit knowledge at individual level without specifying any specific language creates knowledge. For example, children imitate the behavior of their parents and learn from it. This is followed by an externalization mode where tacit knowledge is transformed into explicit knowledge. Written reports coming from lessons learned gained in form of experiences and impressions are an example of externalization. In combination, knowledge is gained by pooling isolated and existing pieces of explicit knowledge into a holistic system structure. Fundamentally, combination is a social process that leverages communicable property of explicit knowledge. The final mode of spiral is internalization where explicit knowledge is absorbed by individuals.

Explicit knowledge is applied multiple times enriching tacit knowledge base by including them in habits and daily routines. This model not only generate knowledge but also entails activities to support the inherit knowledge transfer at individual and organizational level to physically realize in the product and processes. Here, knowledge creation occurs through a nexus of interaction within team members, problem solving actions, and tasks performed. Existing knowledge of an organization is exploited in dealing with the problems by exploring, defining and developing the solution. During problem solving exercises, both environment and organization interact and absorb the required changes to gain new knowledge. An organization possess a stock of technology which can become irrelevant in future. Gained new experiences, and their application in any form for others to use are major resources for survival. Nonaka [5] presented an argument that dialectical thinking plays an important role in transcending and synthesizing contradictions which ultimately leads towards new knowledge creation.

4. Problem formulation

The vital ingredient for creative PD is employee's knowledge base that actually determines and adds value. Additionally, such decisive knowledge is of paramount importance in shortening the development cycle and reducing the expenditure of unplanned risks. This puts pressure on organizations to effectively create, update, and handle knowledge. In this context, effect of SECI modes on development phase from knowledge creation perspectives are investigated. This helps a team to make informed-strategic decisions to improve their performance.

4.1. Development phase

Investment in quality improvement efforts at development phase is ten times more effective than during production phase

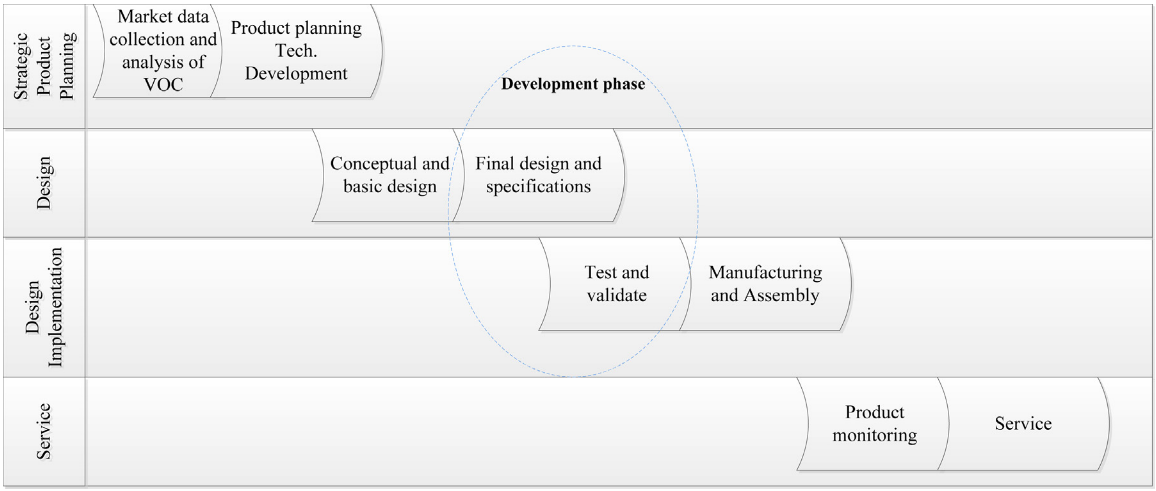

Fig. 1. The PD process and high level steps considered under development phase.

[39]. This phase lies between concept phase and manufacturing phase (see Fig. 1). During development phase, customer requirements are transformed into concrete deliverables in form of product designs and their application in real settings are validated. The successful completion of this phase requires a complete set of design specifications and proper description of processes, standards, and tools [40,41]. The emphasis is also given on meeting quality, time, and schedule objectives. The details of identified criteria and sub-criteria are discussed next.

4.2. *Important criteria/sub-criteria during development phase*

Intensive review of available research and a prolonged discussion with SMEs from strategic decision areas are conducted before picking the top five criterions. These criteria are further divided into nineteen important sub-criteria. The applicability of each sub-criterion for development phase is detailed next.

4.3. *Final design*

The product and process designs directly affect the performance of development phase. This is due to the fact that collectively they determine a major portion of manufacturing costs [42]. Before confirming the design, all planned approaches and activities for integration of hardware, software, and other components are tested. Design rules, and technologies are specified and/or acquired and final details of product/process architecture are established and documented while performing the necessary research work. This helps in defining the arrangement of a functional system and their behavior as a unit. Current product variant(s) is another criterion that affects the performance of development phase. The relative position of the final product specifications with respect to competitor's and own product portfolio should be assessed by gathering pertinent information. Having a product with meaningful characteristics better than competitors increases the likelihood of commercial success.

4.3.1. *Product design (DD)*

Development phase ensures that established final product design meets all the business needs and has been benchmarked with other designs. Furthermore, general product characteristics such as part material, product configuration, surface finish, and tolerances are also finalized. The bottom line is that after successful development phase, the final design must reflect the customer needs, differentiate the product from the competition, and demonstrate technical and economic feasibility of a ready to launch product [40–43].

4.3.2. *Process design (SD)*

The general characteristics affecting process design such as part handling, tooling type, and operations sequencing must be determined. Process design is a critical phase that typically occurs concurrently with the product design [44]. It focuses on increasing productivity by eliminating risk of losing value through inappropriate operation activities. The process design should be optimized to support and sustain organizational growth. It may need a tweak (modest changes) into existing processes for some quick wins or radical changes to accommodate aggressive alterations.

4.3.3. *Product portfolio (PF)*

The product portfolio basically encompasses all variant(s) of a product that an organization is developing and producing. An engineer working on more than one product can create knowledge and apply it for improving development phase performance. For example, tacit knowledge gained during activities of one product can bring different perspectives to take well-informed decisions [45]. The overall goal is to implement accumulated organizational knowledge and/or technical knowledge from one product variant to other during development phase.

4.4. *Reusability*

Reusability is required for efficient handling of the development phase. The development team should write comprehensive, and easy to understand documents with no redundant information for other teams and future reuse. Such collected information from documents of past projects should be recycled and integrated with current projects where it's possible and beneficial. This is intended to save time and business efforts for current projects [46].

4.4.1. *Project briefings (PB)*

In project briefings, present project team learns from seasoned employees of the past projects typically in a workshop. The seasoned employees share important issues faced by them in a structured way with examples and illustrations. This is primarily done to share relevant technical issues or problems and other objectives such as cost, time and quality [47].

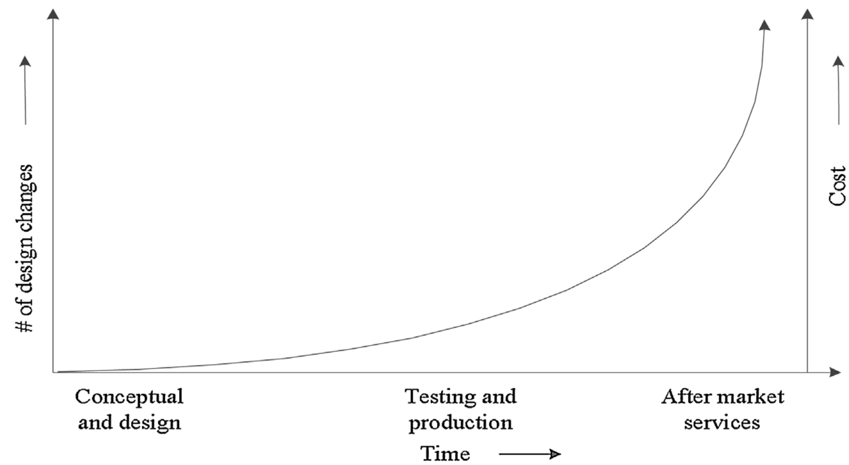

Fig. 2. The change in cost between front end vs back end.

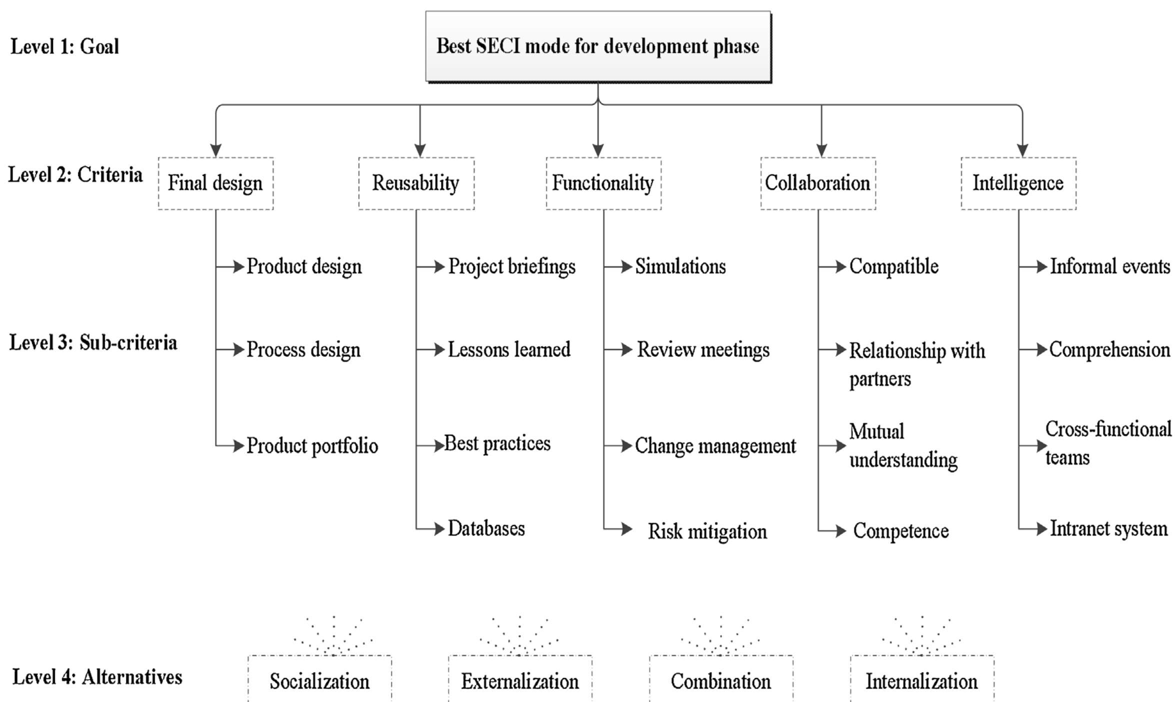

Fig. 3. Hierarchical structure of ranking the SECI modes for development phase.

4.4.2. Lessons learned (LL)

The critical project information and other deliverables, irrespective of positive or negative experiences, from all life-cycle phases should be organized and documented in a repository for easy access, store, and reference. These documents should also include information related to any preparation before development or modification of a product and other item [47]. The objective is to capture the valuable knowledge revealed during the past projects and their learning by the team members. The documentation of lessons learned for future projects should be supported and use of these lessons learned from past projects should be promoted.

4.4.3. Best practices (BP)

The best practices are characterized by the description of effective processes in successfully completing the same task multiple times. Before selecting any practice as a best practice, several common and good practices should be compared. The description of best practices should have a problem statement, relevant circumstances, solution steps, and required information specifications to conduct the tasks [48]. The best practices should be understood in details and modified before considering them into other perspectives. Documentation and necessary modification of best practices should be supported for wider applicability.

4.4.4. Databases (DB)

Extensive calculations and simulations are performed for testing. The outcomes should be systematically recorded to assist future developments. A disciplined approach to analyze data reduces time in data management, information consistency, and turns disparate information into a valuable resource. The databases must be kept current, and coded for seamless and intuitive accessibility [49]. The database offers knowledge to make the right and accurate decisions.

4.5. Functionality

As mentioned earlier, part functions/properties and their interaction must be identified, correlated and analyzed with product requirements. As a result, the user may need to flow down the specifications and further refine them as appropriate, reflect them on the product/process and make trade-offs where necessary. Additionally, the technical and cost models of the product must be developed while establishing the final specifications [40]. With their help product concepts are exercised before selecting the final design. For continuous innovation, functionality is vital in identifying required properties and transforming them into actions.

4.5.1. Simulations (SM)

An engineer performs integrated calculations of stress, deflection, and motion to validate designs in a simulation by evaluating how moving parts interact and design functions under real settings. Engineers create documentations which are required by the production team to perform accurate analysis and evaluation. Effective use of simulation ensures best possible design decisions to sharply reduce uncertainty and risks. A simulation also testes and validates prototypes to enhance the confidence regarding absence of serious problems in future [50]. Moreover, digital prototypes can be tested immediately under realistic conditions. The digital prototyping speeds up the development cycles by eliminating the need of a physical prototype.

4.5.2. Review meetings (VM)

Review meetings are convened to present designs and to gain multi-disciplinary opinions. In these meeting, designs are appreciated, critiqued, peer reviewed to investigate its existing capabilities and deficiencies [51]. Further action plans are developed and formulated to implement routine deliverable reviews to correct inaccuracy, incompleteness, and ambiguities [52]. These meetings also provide means for assessing progression to the next stage of development or testing.

4.5.3. Change management (CM)

Change management deals how these changes are planned, communicated, analyzed, implemented, and released as the product evolves. Complex PD process and upfront lack of knowledge forces users to avoid or bypass changes only to find out at the later stages. A high number of cross-functional teams further complicate the situation. Loss of the valuable design and configuration results in incomplete or incorrect knowledge/documentation causing severe problems for downstream stages [53]. This is owing to the fact that making changes in the front end of the design process is easier but as product matures, complexity and cost of changes increases exponentially (see Fig. 2). Documenting changes and their causes/solution for future reuse are required for efficient change coordination.

4.5.4. Risk mitigation (RM)

Activities of identifying, analyzing and managing the risks are conducted to stop a product from failures. Initial risks affecting the product and their characteristics are identified. Next, each risk is analyzed using quantitative and/or qualitative analysis. The details of risk analysis method and conditions are also described. Furthermore, response plans and strategies are developed to mitigate, transfer or avoid them. In the end, procedures to monitor and control the identified and new risks are defined [54]. Risk mitigation requires identifying them within whole life-cycle and knowledge to analyze and align them with other departments for efficient management.

4.6. Collaboration

Collaboration enables the process of human interactions for decision-making in the organizational context. Knowledge artifacts serve as a medium of interaction between a team of co-workers and/or among stakeholders. Procurement of appropriate systems and services through collaborative efforts demonstrate a clear value for business case. The pre-requisite factors for an efficient collaboration are professional relationship with partners, structured organization recognition and reward systems, superior leadership models and practices, and team competencies. Collaboration is a norm in companies for successful and innovative future.

4.6.1. Compatible (CO)

A newer version of a product is considered compatible when design and/or data of an older version of the same product build it. The importance is vindicated by the fact that it eliminates the need to start over when older version is upgraded (which is true in most cases in present scenarios). This generally forces an organization to keep products compatible across multiple-generations. It is also necessary to sacrifice compatibility to exploit modern technologies.

4.6.2. Relationship with partners (RP)

The decision of producing the components in-house or purchasing must be determined and suppliers should be identified upfront. Suppliers and customers share ideas, provide/receive critical feedback and a tremendous amount of knowledge is exchanged. As acquisition of tacit knowledge is important, the relationship strength greatly influences the end product performance [55]. Acquiring such knowledge from partners is necessary in today's uncertain environment. Partner's understanding of a firm's vision to develop a long-term partnership is also required.

4.6.3. Common understanding (CU)

Ensuring that there is a common understanding regarding product, process design etc. among team members and stakeholders is imperative. Common understanding supports sharing of experiences, and values to enhance mental models and technical skills in the uncertain business environments. Records can be used to emphasize the opportunities of adapting and integrating them with decisions of other projects on an ongoing basis. This helps in nurturing the common understanding among employees and integrating knowledge from other projects.

4.6.4. Competence (CT)

Employees are the most important assets of an organization and core competencies they possess are needed to face current and future challenges. Critical thinking, communication, and stewardship are among the top competencies required [56]. These core competencies aid in identifying and evaluating the right opportunities important for growth of an organization.

4.7. Intelligence

A new employee has a relatively steep learning curve owing to possibly different working culture, product, and processes. They rarely receive any manual to demonstrate how work is done internally. If they receive something, the manuals generally are either very comprehensive or very scarce [57]. A precise yet dynamic tool that can offer a new employee a work form, and contribute in augmenting individual's abilities and expertise is important. The team members throughout company can easily learn and quickly bridge the learning cycle gap.

4.7.1. Informal events (IE)

Open communication and discussion during informal events encourage transfer of tacit knowledge among team members. The entire company workforce from all locations should come together after a constant period for this purpose. It is worthwhile to build the personal networks and knowledge exchange even at a significant cost [47]. This exercise results in nurturing confidence among teams to arrive at new insights and more accurate interpretations as opposed to individuals. Team builds better solutions that help in resolving issues quickly and increase job satisfaction for team members. Therefore, the performance of a project is likely to improve [15].

4.7.2. Comprehension (CH)

Comprehension encompasses the process of gaining intelligence from interaction with the external environment. The resulting intelligence is combined with other projects regularly in order to identify problems, and opportunities. It follows "learning by doing" or re-experiencing philosophy to transform the explicit knowledge into tacit knowledge [58]. The comprehension by incorporating the documented approaches into mental models should be supported.

4.7.3. Cross-functional teams (CF)

A group of people working together who collectively represent the interests of an organization is called a cross-functional team. Strong and healthy cross-functional teams are imperative for broad communication, easy alignment of goals and improved products to dominate the market against competition [59]. The successful cross-functional team enhances creativity and innovation, quickens problem solving, and escalates learning [60]. While working as a team, individual easily get and access updated information and brings up encountering issues or roadblocks to enhance useful capabilities in broader way and update documents.

4.7.4. Intranet system (IS)

The intranet system primarily contains knowledge elicitation, access to expert problem solvers, and reporting. The vast knowledge in intranet system acts as a learning guide or an online coach for users to solve problems by following a rigorous reasoning process [61]. Intranet system is advocated to define new problems and countermeasures or append them with the existing ones. The process progresses in stages to lead towards either an already explored permanent countermeasure or an unidentified/unsolved problem. The temporary fixes of the closed problems are documented in intranet system and others (unsolved problems) are either removed or integrated into the permanent countermeasures. Questions are formatted in a specific sequence to elicit user's reasoning. This reasoning from gained experience reflects their perspectives on the situation's unique context [62]. Furthermore, written down documents allow others to access the wealth of tacit knowledge applied into problem solving. The hierarchical structure of the underlying problem is summarized in Fig. 3.

5. Proposed methodology – the EFAHP approach

The EFAHP approach is relevant to solve the problem at hand considering multi-criteria structure and vagueness in real environment. This systematic approach basically integrates two fundamentally distinct concepts, the fuzzy set theory and the AHP. The advantage of fuzzy set theory is in dealing with the ambiguity intrinsic to the decision-making problems and the ability to define vague data using classes and grouping with boundaries [63]. The fuzzy extension is required because the basic AHP misses the important aspect of tackling the high degree in vagueness of personal subjective judgments and preferences. EFAHP approach represents the linguistic variables of human feelings and judgments by a TFN for conducting the pairwise comparisons. The pairwise comparison utilizes a membership function (Eq.(1)) to determine the relative importance of two criterions. Implementation steps of EFAHP method are detailed next.

Step1: Develop fuzzy comparison metrics

The decision-maker is asked to facilitate the comparison of one criterion over another in linguistics terms while keeping the overall goal in mind. Here a simple question is asked: according to him/her "how important is one criterion (for example criterion μ_1) over another (μ_2) in terms of primary goal." The user can simply put them as criterion μ_1 is fairly important as compared to criterion μ_2. The linguistic terms corresponding to Saaty's scale, their definition and TFN are shown in Fig. 4. The comparisons in linguistic terms are shown in Table 2. According to the table, TFN value for this comparison is (4, 5, 6). However, when criterion μ_2 is compared against μ_1 TFN changes to (1/6, 1/5, 1/4).

Step 2: Calculate fuzzy synthetic extent value (E_c)

If $\tilde{T}_1 = (t_{11}, t_{12}, t_{13})$ and $\tilde{T}_2 = (t_{21}, t_{22}, t_{23})$ are two TFNs then the fuzzy addition (+) or fuzzy subtraction (−), fuzzy multiplication (⊗), fuzzy division (—) operations of two TFNs and fuzzy inverse operation ($[]^{-1}$) of a TFN as discussed in Chang et al. [12] are followed.

E_c for c^{th} criterion with respect to any object (o) is estimated by Eq. (2)

$$E_c = \sum_{a=1}^{p} T_{oc}^{a} \otimes \left[\sum_{b=1}^{q} \sum_{a=1}^{p} T_{oc}^{a} \right]^{-1} \tag{2}$$

Where, T_c^a (a = 1, 2 . . ., p) denotes a TFN and object o = (1, 2, 3). The value of $\sum_{a=1}^{p} T_c^a$ is estimated by adding the fuzzy values for p extent analysis using addition operation.

$$\sum_{a=1}^{p} T_c^a = \left(\sum_{a=1}^{p} t_{a1}, \sum_{a=1}^{p} t_{a2}, \sum_{a=1}^{p} t_{a3} \right) \tag{3}$$

$$\sum_{b=1}^{q} \sum_{a=1}^{p} T_c^a = \left(\sum_{b=1}^{q} t_{b1}, \sum_{b=1}^{q} t_{b2}, \sum_{b=1}^{q} t_{b3} \right) \tag{4}$$

$$\left[\sum_{b=1}^{q} \sum_{a=1}^{p} T_c^a \right]^{-1} = \frac{1}{\sum_{b=1}^{q} t_{b3}}, \frac{1}{\sum_{b=1}^{q} t_{b2}}, \frac{1}{\sum_{b=1}^{p} t_{b1}} \tag{5}$$

Step 3: Determine the comparative superiority

The comparative superiority of one TFN $\left(\tilde{T}_1 = t_{11}, t_{12}, t_{13}\right)$ over another TFN $\left(\tilde{T}_2 = t_{21}, t_{22}, t_{23}\right)$is defined as $S(\tilde{T}_1 \geq \tilde{T}_2) = \min\left(\lambda\left(x|\tilde{T}_1\right), \lambda\left(y|\tilde{T}_2\right)\right)$. Where, a combination of (x, y) is such that they follow $x \geq y$ and for some combination of x and y there exists$\lambda\left(x|\tilde{T}_1\right) = \lambda\left(y|\tilde{T}_2\right) = 1$. From here on, the tilde is removed from T_1 and T_2, just to simplify the representation and analysis. Since T_1 and T_2 are convex fuzzy numbers (Chang [12]), therefore,

$S(T_1 \geq T_2) = 1$ iff $t_{11} \geq t_{21}$ (6)

for the same combination of $t_{11} \geq t_{21}$ $S(T_2 \geq T_1) = hgt(T_2 \cap T_1) = \lambda(d|T_1)$ (7)

Where, d is the point of highest interaction between two TFNs. The ordinate for such two triangles ($T_1 = t_{11}, t_{12}, t_{13}$) and ($T_2 = t_{21}, t_{22}, t_{23}$)is estimated using Eq. (7) if $t_{21} \geq t_{11}$ and t_{11}-$t_{23} \leq 0$.

$$hgt(T_2 \cap T_1) = \frac{(t_{11} - t_{23})}{(t_{22} - t_{23}) - (t_{12} - t_{11})} \tag{8}$$

The values of for both $S(T_1 \geq T_2)$ and $S(T_2 \geq T_1)$ must be calculated in order compare T_1 and T_2. Where, hgt (.) function defines

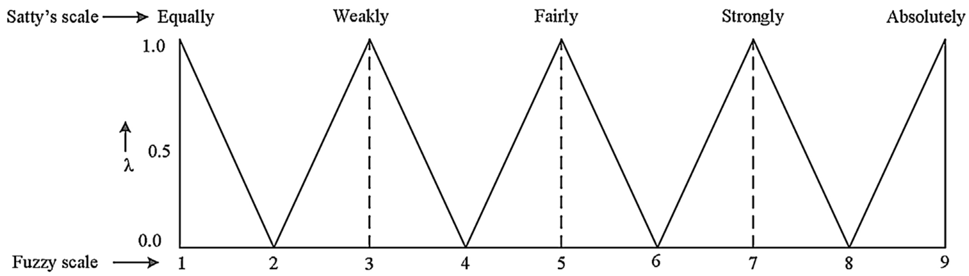

Fig. 4. Fuzzy definition and TFN corresponding to Saaty's scale.

Table 1
Pairwise comparison of criterion to determine metrics with respect to the overall goal.

A(9,9,9)	S(6,7,8)	F(4,5,6)	W(2,3,4)	Criterion	E(1,1,1)	Criterion	W(2,3,4)	F(4,5,6)	S(6,7,8)	A(9,9,9)
	X			Reusability		Final design				
		X		Functionality		Final design				
				Collaboration		Final design		X		
	X			Intelligence		Final design				
				Functionality		Reusability		X		
				Collaboration		Reusability		X		
				Intelligence		Reusability			X	
			X	Collaboration		Functionality				
				Intelligence		Functionality		X		
				Intelligence		Collaboration	X			

the intersection height of two different triangle at the intersection point. Eq. 6 and Eq. 8 are summarized in Eq. (9).

$$S(T_2 \geq T_1) = \left(\begin{array}{ll} \dfrac{(t_{11} - t_{23})}{(t_{22} - t_{23}) - (t_{12} - t_{11})} & t_{11} \geq t_{21} \,\&\, t_{11} - t_{23} \leq 0 \\ 0 & Otherwise \end{array} \right) \tag{9}$$

The resulting value of Eq. (9) is employed to estimate the comparative superiority of one TFN over another when they intersect. The situation where two TFNs don't intersect (t_{11}-$t_{23} \geq 0$) is illustrated in Fig. 5. In this figure, two TFNs are mapped with normal distributions extended with respect to X-axis so that they cut at point d' as represented by the dotted lines. These extended edges of normal distributions are considered to compute the comparative superiority of two criterions [64]. A method to calculate the value of degree of possibility for two TFNs not intersecting with each other is proposed in this paper. The three-point estimates are used to calculate the approximate values of mean (μ) and standard deviation (σ) of a normal distribution. The most likely value (t_{12}) provides the mean value of a normal distribution and standard deviation can be estimated using Eq. (10).

$$\text{The standard deviation}\,(\sigma) = \sqrt{\frac{(t_{23} - t_{11})^2}{36}} \tag{10}$$

For the analysis purpose, first the parameters of normal distribution from three-points are estimated. Then, the two normal distributions are drawn on MATLAB to find out the point of intersection on X-axis and height of intersection (h_{nd}). This height provides the true degree of superiority of one sub-criterion over another when triangles are not intersecting (see Fig. 6). Therefore, Eq. (9) is updated to Eq. (11).

$$S(T_2 \geq T_1) = \left(\begin{array}{ll} \dfrac{(t_{11} - t_{23})}{(t_{22} - t_{23}) - (t_{12} - t_{11})} & t_{21} \geq t_{11} \,\&\, t_{11} - t_{23} \leq 0 \\ h_{nd} & Otherwise \end{array} \right) \tag{11}$$

Step 4: Select the minimum value of superiority

$$S\,(T \geq T_1, T_2, \ldots, T_l) = S\left\{(T \geq T_1) \text{ and } (T \geq T_2) \text{ and } \ldots \text{ and } (T \geq T_l)\right\} \tag{12}$$

$$= \min S\left\{(T \geq T_i)\right\} \tag{13}$$

where, $i = 1, 2, \ldots, l$

Step 5: Calculate weight vector and normalize it for each criterion

$$\mathrm{m}(\pi_l) = \min \mathrm{S}(\mathrm{E_i} \geq \mathrm{E_l}) \text{for} \forall i = 1, 2, \ldots, l; excepti = l \tag{14}$$

Then, the weight vector is estimated as

$$\mathrm{Wp} = \{\mathrm{m}(\pi_1),\ \mathrm{m}(\pi_2), \ldots, \mathrm{m}(\pi_\mathrm{i})\}^\mathrm{T} \tag{15}$$

This weight is normalized, and the normalized weight vector is expressed using Eq. (16).

$$\mathrm{W} = \{\mathrm{w}(\pi_1), \mathrm{w}(\pi_2), \ldots, \mathrm{w}(\pi_\mathrm{i})\}^\mathrm{T} \tag{16}$$

Step 6: Repeat step 1 to 5 to determine the normalized weight vector of the sub-criteria in response to the criteria. Furthermore, estimate the normalized weight of alternatives corresponding to each sub-criterion.

Step 7: Multiply the normalized weight vector values of alternatives with that of sub-criteria and add them in order to estimate the partial priority weight of an alternative.

Step 8: Multiply the normalized values of the criteria with the multiplication values of alternative and sub-criteria estimated in Step 7 and add them to estimate the final priority weight. Mode with highest final priority weight value has the most influence on the development phase.

6. Numerical example and analysis

The PD process follows a sequence of activities, deliverables, methods and tools to design and develop high quality products that exceeds customer expectations [44]. The development phase predominately has activities pertaining to developing a mature concept design. The engineering work remained is to complete and

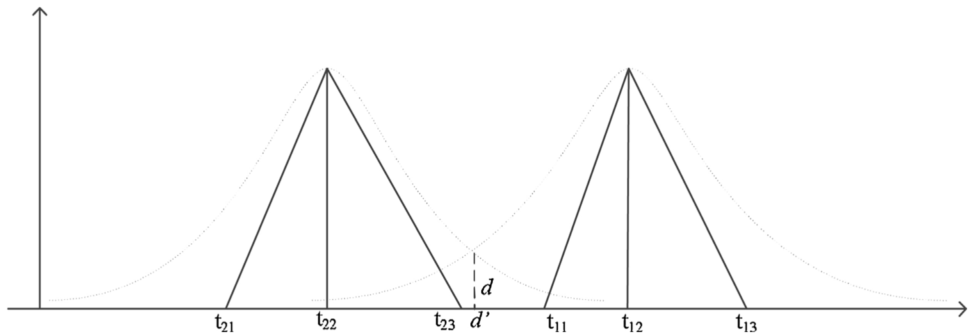

Fig. 5. Extension of two triangles to normal distributions when they don't intersect.

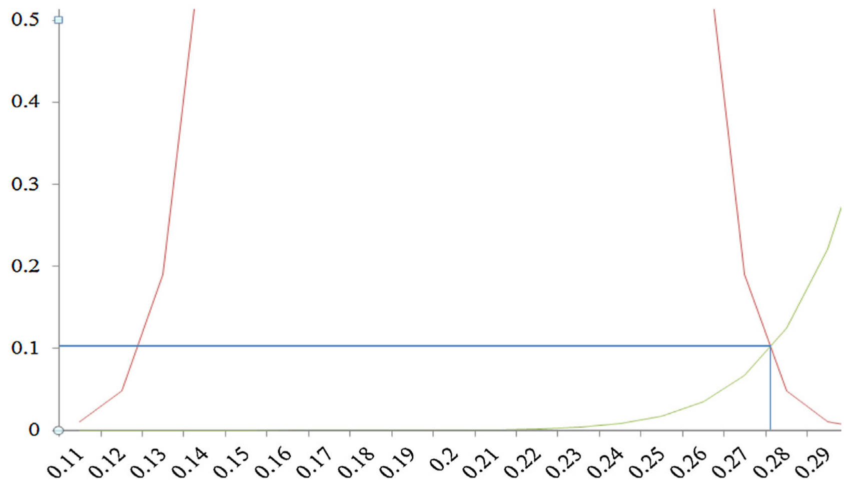

Fig. 6. The intersection point of two normal distributions.

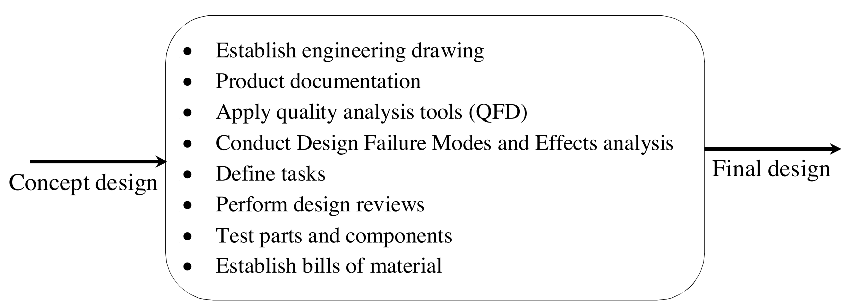

Fig. 7. Input, output, and tasks of the development phase.

test the detailed parts and modules. The major deliverables include established engineering drawing, documented product information, applying quality analysis tools such as QFD, conducting Design Failure Modes and Effects analysis, design reviews, testing parts and establishing the bill of material (see Fig. 7).

Therefore, designers are no longer merely exchanging geometric data, but more general knowledge about design and design process, including specifications, design rules, constraints, rationale etc. are shared [41]. During execution of these tasks, fresh requirements are targeted to achieve. For this, existing knowledge from past projects is not sufficient, resulting in new obstacles in form of the unfamiliar and unsolved problems. In order to solve them, engineers wonder around and struggle in selecting the right tool to reach the solution. Ultimately the problems are solved in practical settings but in this competitive environment, time is the decisive factor. Knowledge creation ability to quickly resolve an unfamiliar issue is critical. A list of established customized tools to choose from for a specific phase to support knowledge creation and transfer can become handy in minimizing the business efforts. Therefore, organizations are interested in comprehensibly evaluating the SECI modes for proper utilization of resources in order to achieve critical but relatively important goals.

This article attempts to present a mathematical model to solve the problem in a realistic environment. For this, first the overall goal and what an organization is trying to accomplish are finalized. Next criteria and sub-criteria critical in achieving the overall goal are identified (see Section 3). Handling more than 7–9factors simultaneously is cumbersome in accurate decision-making. The complex problem (selecting the best mode that positively affects the development phase) is broken down into four hierarchical levels for ease in managing the analysis. The first level in hierarchy is goal which is to select the best SECI mode(s) for development phase. Next in hierarchy are criteria at second level, followed by sub-criteria at third level, respectively. The alternatives (SECI modes) are placed at

Table 2
Metric values for criteria with respect to overall goal.

Criterion	Final Design	Reusability	Functionality	Collaboration	Intelligence	Weight
Final Design	(1,1,1)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(4,5,6)	(1/8,1/7,1/6)	0.08
Reusability	(6,7,8)	(1,1,1)	(4,5,6)	(4,5,6)	(6,7,8)	0.43
Functionality	(4,5,6)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(4,5,6)	0.04
Collaboration	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(2,3,4)	0.20
Intelligence	(6,7,8)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	0.25

the bottom or fourth level of hierarchy (see Fig. 2). Once hierarchy was formed, EFAHP approach is exploited to estimate the priority weights of criteria, sub-criteria and alternatives. The method for calculating the priority weights with respect to overall goal is demonstrated in this section.

Step1: The pairwise comparison of different criterion against the overall goal is conducted to construct the fuzzy comparison matrix (Table 1) and then priority value of each criterion with respect to the overall goal is calculated (Table 2).

Step 2: Eq. (5) is employed to estimate E_1, E_2, E_3, E_4 and E_5 for each criterion.

$E_1 = (5.42, 6.49, 7.58) \otimes (48.71, 59.10, 69.75)^{-1} = (0.08, 0.11, 0.16)$

$E_2 = (21.0, 25.0, 29.0) \otimes (48.71, 59.10, 69.75)^{-1} = (0.30, 0.42, 0.59)$

$E_3 = (9.42,\ 11.53,\ 13.75) \otimes (48.71,\ 59.10,\ 69.75)^{-1} = (0.14,\ 0.20,\ 0.28)$

$E_4 = (5.33, 7.40, 9.50) \otimes (48.71, 59.10, 69.75)^{-1} = (0.08, 0.13, 0.19)$

$E_5 = (7.54, 8.68, 9.92) \otimes (48.71, 59.10, 69.75)^{-1} = (0.11, 0.15, 0.20)$

Step 3: Eq. (11) are used to calculate the comparative superiority value of E_i over E_j ($i \neq j$).

$S(E_1 \geq E_2) = 0.22$ (calculated using intersection of two normal distribution);

$$S(E_1 \geq E_3) = \frac{(0.135\ -0.156)}{(0.11-0.156)-(0.195-0.135)} = 0.19$$

$$S(E_1 \geq E_3) = \frac{(0.076\ -0.156)}{(0.11-0.156)-(0.125-0.076)} = 0.84$$

$$S(E_1 \geq E_3) = \frac{(0.108\ -0.156)}{(0.11-0.156)-(0.147-0.108)} = 0.56$$

$$S(E_2 \geq E_1) = 1S(E_2 \geq E_3) = 1S(E_2 \geq E_4) = 1S(E_2 \geq E_5) = 1$$

$$S(E_3 \geq E_1) = 1S(E_3 \geq E_2) = 0.09S(E_3 \geq E_4) = 1S(E_3 \geq E_5) = 1$$

$$S(E_4 \geq E_1) = 1S(E_4 \geq E_2) = 0.55S(E_4 \geq E_3) = 0.46S(E_4 \geq E_5) = 0.80$$

$$S(E_5 \geq E_1) = 1S(E_5 \geq E_2) = 0.55S(E_5 \geq E_3) = 0.59S(E_5 \geq E_4) = 1$$

Step 4: Using Eq. (18), minimum degree of superiority for each criterion is obtained.

min (π_1) = *min* $S(E_1 \geq E_2,\ E_3,\ E_4,\ E_5)$ = *min* (0.87, 0.19, 0.84, 0.56) = 0.19

Similarly, *min* $(\pi_2) = 1.00$, *min* $(\pi_3) = 0.09$, *min* $(\pi_4) = 0.46$, *min* $(\pi_5) = 0.55$

Step 5: The weight vector with respect to criterion is estimated as

$$Wp = (0.19, 1.00, 0.09, 0.46, 0.55)^T$$

The normalized weight vector (W) is = $(0.09, 0.43, 0.04, 0.20, 0.24)^T$

Step 6: Steps 1–5 are repeated to determine the normalized weights of sub-criteria in response to criteria and that of alternatives with respect to sub-criteria (See Tables 3–7)

Table 3
Metric values with respect to final design.

	DD	SD	PF	Weight
DD	(1, 1, 1)	(4, 5, 6)	(6, 7, 8)	0.39
SD	(1/6, 1/5, 1/4)	(1, 1, 1)	(4, 5, 6)	0.07
PF	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.54

Table 4
Metric values with respect to reusability.

	PB	BP	LL	DB	Weight
PB	(1, 1, 1)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/4, 1/3, 1/2)	0.05
BP	(2, 3, 4)	(1, 1, 1)	(4, 5, 6)	(2, 3, 4)	0.56
LL	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/4, 1/3, 1/2)	0.10
DB	(2, 3, 4)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1, 1, 1)	0.28

Table 5
Metric values with respect to functionality.

	SM	RM	CM	VM	Weight
SM	(1, 1, 1)	(1/6, 1/5, 1/4)	(2, 3, 4)	(2, 3, 4)	0.31
RM	(4, 5, 6)	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)	0.31
CM	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 1, 1)	0.19
VM	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 1, 1)	0.19

Table 6
Metric values with respect to collaboration.

	CO	RP	CU	CT	Weight
CO	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)	(9, 9, 9)	0.18
RP	(1/6, 1/5, 1/4)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	0.28
CU	(1/6, 1/5, 1/4)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	0.38
CT	(1/9, 1/9, 1/9)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.16

Table 7
Metric values with respect to intelligence.

	IE	CF	PS	IS	Weight
IE	(1, 1, 1)	(1/9, 1/9, 1/9)	(1/6, 1/5, 1/4)	(1/9, 1/9, 1/9)	0.52
CF	(9, 9, 9)	(1, 1, 1)	(4, 5, 6)	(1, 1, 1)	0.29
PS	(4, 5, 6)	(1/6, 1/5, 1/4)	(1, 1, 1)	(2, 3, 4)	0.08
IS	(9, 9, 9)	(1,1,1)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.11

6.1. Criterion against the sub-criterion

Step 7: Partial priority weight for combination mode is estimated as (see Tables 8–26): {(0.39*0.58 + 0.07*0.26 + 0.54*0.32), (0.05*0.55 + 0.56*0.55 + 0.10*0.56 + 0.28*0.49), (0.31*0.59 + 0.31*0.41 + 0.19*0.45 + 0.19*0.41), (0.18*0.49 + 0.28*0.35 + 0.38*0.50 + 0.16*0.43),

Table 8
Metric values with respect to DD.

DD	S	E	C	I	Weight
S	(1,1,1)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(2, 3, 4)	0.01
E	(2, 3, 4)	(1,1,1)	(1,1,1)	(4,5,6)	0.30
C	(6,7,8)	(1,1,1)	(1,1,1)	(4,5,6)	0.58
I	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1,1,1)	0.11

Table 9
Metric values with respect to SD.

SD	S	E	C	I	Weight
S	(1, 1, 1)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.22
E	(1, 1, 1)	(1, 1, 1)	(1/8, 1/7, 1/6)	(4,5,6)	0.26
C	(6, 7, 8)	(6, 7, 8)	(1, 1, 1)	(6, 7, 8)	0.26
I	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.26

Table 10
Metric values with respect to PF.

PF	S	E	C	I	Weight
S	(1, 1, 1)	(2, 3, 4)	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	0.17
E	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	0.32
C	(6, 7, 8)	(6, 7, 8)	(1, 1, 1)	(2, 3, 4)	0.32
I	(4,5,6)	(6, 7, 8)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.18

Table 11
Metric values with respect to PB.

PB	S	E	C	I	Weight
S	(1, 1, 1)	(2, 3, 4)	(1/8, 1/7, 1/6)	(2, 3, 4)	0.01
E	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)	0.22
C	(6, 7, 8)	(1/4, 1/3, 1/2)	(1, 1, 1)	(6, 7, 8)	0.55
I	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.24

Table 12
Metric values with respect to LL.

LL	S	E	C	I	Weight
S	(1, 1, 1)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1/4, 1/3, 1/2)	0.12
E	(2, 3, 4)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	0.16
C	(1/4, 1/3, 1/2)	(6, 7, 8)	(1, 1, 1)	(4, 5, 6)	0.56
I	(2, 3, 4)	(2, 3, 4)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.17

Table 13
Metric values with respect to BP.

BP	S	E	C	I	Weight
S	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	0.09
E	(4, 5, 6)	(1, 1, 1)	(1/4, 1/3, 1/2)	(4, 5, 6)	0.30
C	(6, 7, 8)	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	0.57
I	(2, 3, 4)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.04

Table 14
Metric values with respect to DB.

DB	S	E	C	I	Weight
S	(1, 1, 1)	(6, 7, 8)	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	0.18
E	(1/8, 1/7, 1/6)	(1, 1, 1)	(1/6, 1/5, 1/4)	(4, 5, 6)	0.11
C	(6, 7, 8)	(4, 5, 6)	(1, 1, 1)	(6, 7, 8)	0.49
I	(4, 5, 6)	(1/6, 1/5, 1/4)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.11

Table 15
Metric values with respect to SM.

SM	S	E	C	I	Weight
S	(1, 1, 1)	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	(2, 3, 4)	0.02
E	(6, 7, 8)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.23
C	(2, 3, 4)	(6, 7, 8)	(1, 1, 1)	(4, 5, 6)	0.59
I	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.16

Table 16
Metric values with respect to VM.

RM	S	E	C	I	Weight
S	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	(6, 7, 8)	0.27
E	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	(1, 1, 1)	0.27
C	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/6, 1/5, 1/4)	0.41
I	(1/8, 1/7, 1/6)	(1, 1, 1)	(4, 5, 6)	(1, 1, 1)	0.05

Table 17
Metric values with respect to CM.

CM	S	E	C	I	Weight
S	(1, 1, 1)	(1, 1, 1)	(1/8, 1/7, 1/6)	(4, 5, 6)	0.09
E	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)	0.45
C	(6, 7, 8)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/4, 1/3, 1/2)	0.45
I	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(2, 3, 4)	(1, 1, 1)	0.02

Table 18
Metric values with respect to RM.

VM	S	E	C	I	Weight
S	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(2, 3, 4)	0.16
E	(4, 5, 6)	(1, 1, 1)	(1/6, 1/5, 1/4)	(6, 7, 8)	0.30
C	(2, 3, 4)	(4, 5, 6)	(1, 1, 1)	(6, 7, 8)	0.41
I	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.12

Table 19
Metric values with respect to CO.

CO	S	E	C	I	Weight
S	(1, 1, 1)	(6, 7, 8)	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	0.20
E	(1/8, 1/7, 1/6)	(1, 1, 1)	(1/6, 1/5, 1/4)	(2, 3, 4)	0.02
C	(6, 7, 8)	(4, 5, 6)	(1, 1, 1)	(6, 7, 8)	0.49
I	(4, 5, 6)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.29

Table 20
Metric values with respect to RP.

RP	S	E	C	I	Weight
S	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(6, 7, 8)	0.21
E	(2, 3, 4)	(1, 1, 1)	(4, 5, 6)	(1/4, 1/3, 1/2)	0.27
C	(6, 7, 8)	(1/6, 1/5, 1/4)	(1, 1, 1)	(2, 3, 4)	0.35
I	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1, 1, 1)	0.17

Table 21
Metric values with respect to CU.

CU	S	E	C	I	Weight
S	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	0.09
E	(4, 5, 6)	(1, 1, 1)	(1/4, 1/3, 1/2)	(4, 5, 6)	0.37
C	(6, 7, 8)	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	0.50
I	(2, 3, 4)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.04

$(0.52^*0.47 + 0.29^*0.40 + 0.08^*0.59 + 0.11^*0.50)\} = (0.42,\ 0.53,\ 0.47,\ 0.45, 0.46)$

6.2. *Sub-criterion against the alternatives*

Step 8: Final weight for combination mode is estimated as (see Table 27):

$$\{0.08 * (0.42) + 0.43 * (0.53) + 0.04 * (0.47) + 0.20 * (0.45)$$

Table 22
Metric values with respect to CT.

CT	S	E	C	I	Weight
S	(1, 1, 1)	(4, 5, 6)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.07
E	(1/6, 1/5, 1/4)	(1, 1, 1)	(1, 1, 1)	(1/8, 1/7, 1/6)	0.43
C	(4, 5, 6)	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	0.43
I	(1, 1, 1)	(4, 5, 6)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.07

Table 23
Metric values with respect to IE.

IE	S	E	C	I	Weight
S	(1, 1, 1)	(1/8, 1/7, 1/6)	(4, 5, 6)	(1, 1, 1)	0.13
E	(6, 7, 8)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	0.24
C	(1/6, 1/5, 1/4)	(6, 7, 8)	(1, 1, 1)	(1/6, 1/5, 1/4)	0.47
I	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)	(1, 1, 1)	0.16

Table 24
Metric values with respect to CH.

CH	S	E	C	I	Weight
S	(1, 1, 1)	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	(2, 3, 4)	0.02
E	(6, 7, 8)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.23
C	(2, 3, 4)	(6, 7, 8)	(1, 1, 1)	(4, 5, 6)	0.59
I	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.16

Table 25
Metric values with respect to CF.

CF	S	E	C	I	Weight
S	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1, 1, 1)	0.23
E	(2, 3, 4)	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	0.19
C	(6, 7, 8)	(1, 1, 1)	(1, 1, 1)	(4, 5, 6)	0.40
I	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1, 1, 1)	0.19

Table 26
Metric with respect to IS.

IS	S	E	C	I	Weight
S	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	0.09
E	(4, 5, 6)	(1, 1, 1)	(1/4, 1/3, 1/2)	(4, 5, 6)	0.37
C	(6, 7, 8)	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)	0.50
I	(2, 3, 4)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	0.04

$$+0.24 * (0.46)\} = 0.51$$

The highest score in Table 27 provides the best mode. According to the final score combination mode is the most preferred mode for development phase. The final weights of the different criteria show that the reusability is the most important criteria during development phase, followed by the intelligence, collaboration, final design and functionality.

7. Results and discussion

It is estimated in section VI that combination mode is important for the development phase. Combination mode essentially encourages maintaining expertise or technological knowledge at the enterprise level for a longer period. Collected reports issued by the internal and external agents (e.g., customer, competitor, partner, or government representative) are integrated, classified, reclassified, and synthesized with various existing explicit notions possessed by employees, to form a cluster of organized knowledge resulting in 'systemic explicit knowledge'. In this mode explicit knowledge mentioned in files, databases, networks, and reports is transformed into intricate and organized explicit knowledge to identify innovative products or technologies most likely applicable to be put into practice. The knowledge assets are systemized and packed documentation, manuals, specifications, database, patents and licenses. This article proposes two visual lean tools for fostering the combination mode during development phase. This is owing to the fact that employees have to possess or learn an adequate understanding of each tool and concentrating on deploying a large number of tools can result in negative feedback from employees in terms of utilization. A higher number can draw less interest and lack of usage, which can lead to their banishment in the future. So the optimal number of tools/methods should be enforced to realize the maximum benefits.

Visual tool boards are a powerful way to create knowledge during the combination mode. A3 reports and spaghetti diagrams are two main examples of visual tools. An A3 report is only a single piece of A3 size paper that contains graphs and visual representations instead of large texts. Engineers synthesize, distil, and visualize the knowledge to put a large amount of both tacit and explicit knowledge into compressed form [65]. It helps in integrating and combining old explicit knowledge with new explicit knowledge in the combination mode.

A spaghetti diagram is a tool that indicates the value added and non-value added workflows using a continuous line in visual flow chart format. Traditionally, the lines are hand drawn and follow the workflow during observations. These lines may not be to the exact scale of the actual process. This is because the intention of the tool is to depict the flow of work or material in order to identify and eliminate any non-value-added movements. Improved knowledge creation in combination mode is supported by creative applications of computerized communication networks and large scale databases [6]. These activities should be integrated with the deployment of good and proven practices or procedures, updating files, databases and website, relevant published research and reports to develop new policies and aims. It becomes a powerful tool when it is used with 5S initiatives (5S refers to a workplace organizational methodology based on: sort, systematize, shine, standardize, and sustain). The collected information should be referenced when developing rules, reports for decision-making.

Other practices helpful in combination mode are project briefings, knowledge brokers, and selection of best practices. Project briefings can aid by involving the experienced team to provide knowledge and documents containing issues/results from previous projects. The new requirements can be combined with the knowledge by current team. Generally, best practices can be considered as explicit knowledge if they are noted. They are proven approaches to handle repeating problems or processes effectively, and documented information should be regarded as the major source of communications. Hence, functional specifications of new projects convoluted with explicated experiences or documents from the prior projects results in concrete knowledge creation during combination mode.

Table 27
Final weights of alternatives with respect to overall goal.

Alternative	Criterion																			Final weight	Influence ranking
	RE			RA				FT				CO				IN					
	0.08			0.43				0.04				0.20				0.25					
	DD	SD	PF	PB	BP	LL	DB	SM	RM	CM	VM	CO	RP	CU	CT	IE	CF	CH	IS		
	0.39	0.07	0.54	0.05	0.56	0.10	0.28	0.31	0.31	0.19	0.19	0.18	0.28	0.38	0.16	0.52	0.29	0.08	0.11		
S	0.01	0.22	0.17	0.01	0.01	0.12	0.18	0.02	0.16	0.09	0.27	0.20	0.21	0.09	0.07	0.13	0.23	0.02	0.09	0.13	**4**
E	0.30	0.26	0.32	0.22	0.22	0.16	0.11	0.23	0.30	0.45	0.27	0.02	0.27	0.37	0.43	0.24	0.19	0.23	0.37	0.20	**2**
C	0.58	0.26	0.32	0.55	0.55	0.56	0.49	0.59	0.41	0.45	0.41	0.49	0.35	0.50	0.43	0.47	0.40	0.59	0.50	0.51	**1**
I	0.11	0.26	0.18	0.24	0.24	0.17	0.11	0.16	0.12	0.02	0.05	0.29	0.17	0.04	0.07	0.16	0.19	0.16	0.04	0.16	**3**

The bold value represents the weighted value of each sub-criterion against the S, E, C, I Modes.

8. Conclusion

This paper is the first attempt to conduct a numerical analysis in order to rank the influence of SECI modes on the development phase. For the numerical analysis, an EFAHP approach is proposed to properly analyze the decision variables of higher uncertainty and risks. SMEs expertize is exploited in deciding the criteria and sub-criteria to make the solution industry specific. In order to match a TFN for a specific scenario in the EFAHP (when two triangles are not intersecting), application of a normal distribution is proposed. This assisted us in developing a mathematical formulation to estimate the degree of possibility of two criteria as opposed to zero resulted by the use of the current technique in the literature. As a result, true priority weight of each alternative is calculated. During analysis, it is concluded that combination mode has the most effect on the considered phase. The conclusions drawn from present research after applying EFAHP are in accordance with that of found in the literature. However, application of traditional fuzzy-AHP approach contradicts them. Right ranking of knowledge creation modes helps the development team to make informed-strategic decisions in selecting the relevant lean tools and methods to improve the performance. Such readily available information can play an important role in quickly bringing and expanding the product horizons. Extension of EFAHP approach to other PD phases such as concept design can also provide some interesting insights.

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